

# Profilometry of X-ray Optics: Current Progress

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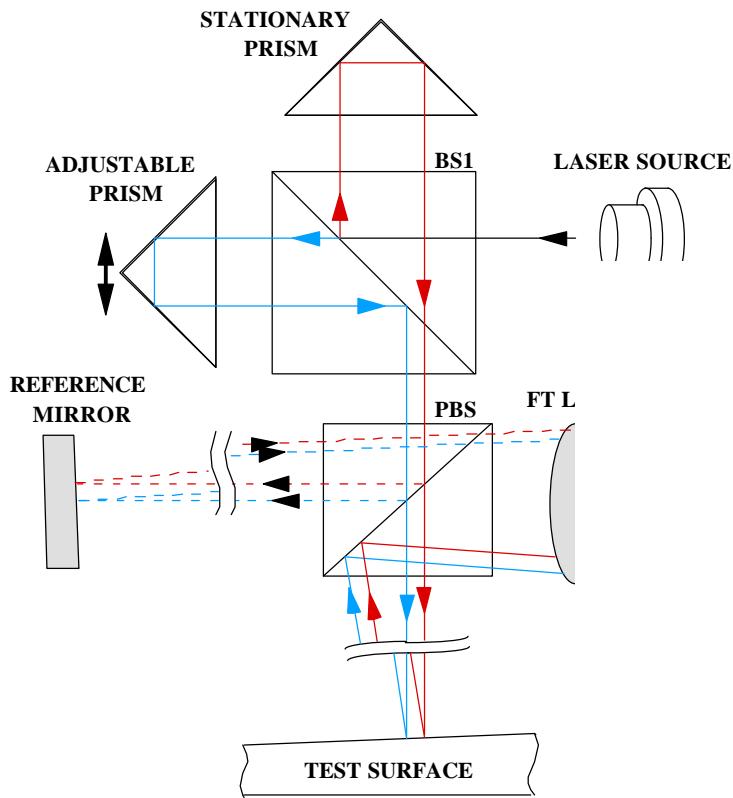
Forensic Metrology Laboratory

Instrumentation Division

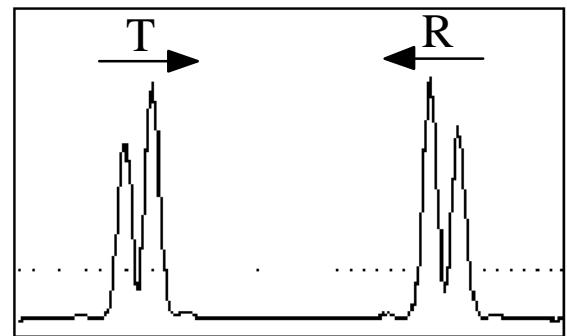
Brookhaven National Laboratory

# Long Trace Profiler

## LTP II Optical Head

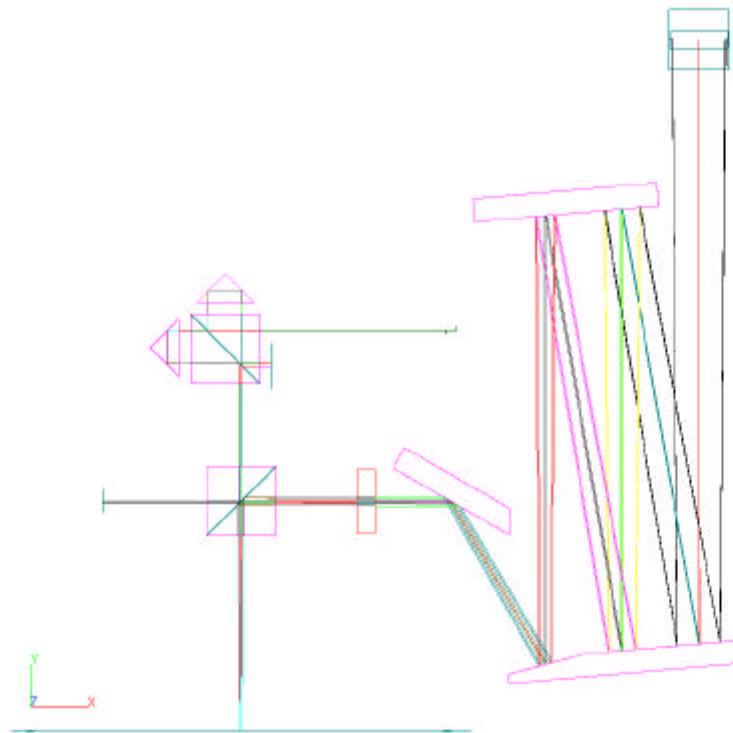


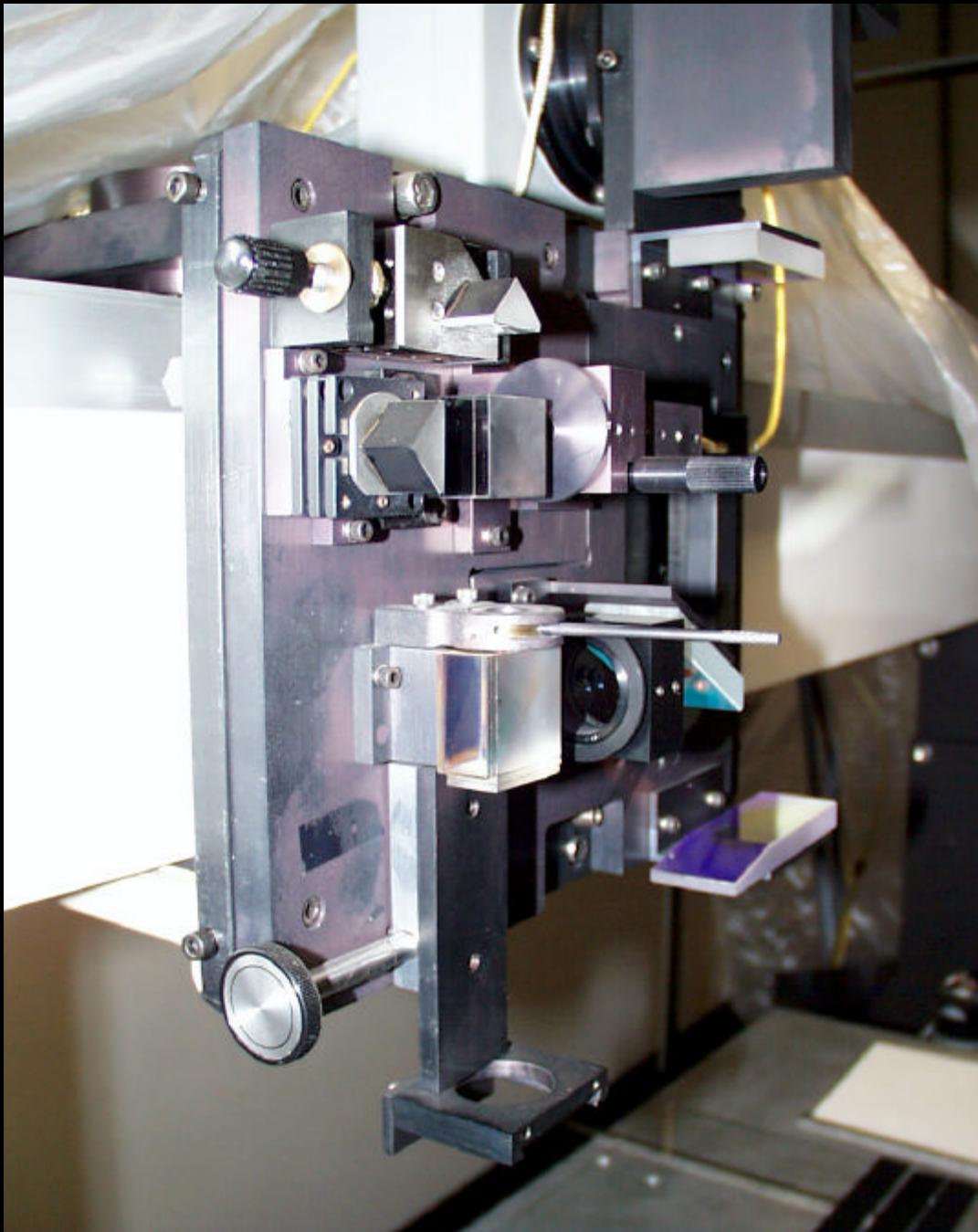
Intensity Fringes on Detector



# LTP II - Optical Model

- Manufactured by Continental Optical Corp. 1991-1999 under license from BNL
- $F = 1250 \text{ mm}$ , Surface Angular Range =  $\pm 5 \text{ mrad}$





# Brief History of the LTP

- 1985 - Begin original design
- 11/87 - LTP I with GPIB detector and stepping motor, **HP BASIC**
- 12/91 - LTP II for LBL from Continental Optical
  - ISA bus PI detector and brushless DC servo motor, **C** and **LabWindows CVI**, **DOS**
- 4/94 - 2/98 - CRADA, SBIR with Continental Optical for NASA VSLTP
  - **C++ version**
- 9/97 - In Situ LTP at Advanced Photon Source
  - 8 bit camera (**DOS**)
- 1/00 - LTP I changed to **HT BASIC** on WinNT PC
- 1/01 - LTP I changed to **LabVIEW**, Dalsa camera&frame grabber
- 6/01 - CRADA with Ocean Optics
  - ELID machine project at RIKEN, Tokyo: OOI detector, **C++ software**
- 11/01 - Portable LTP at SPring8: Cronin camera, motor on parallel port
- 12/01 - Ocean Optics CRADA, Opt head for BESSY

# What's New?

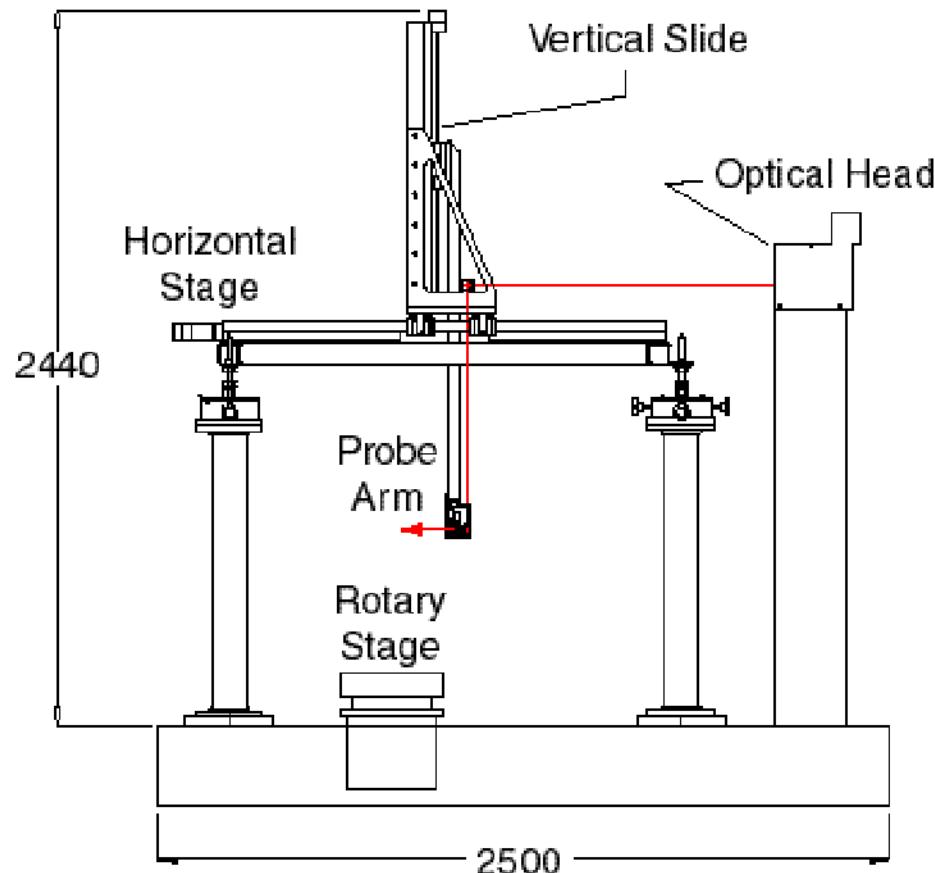
- Switch from Continental Optical to Ocean Optics
  - C++ unified software
  - USB interface for detector and motor
  - Eliminate air bearing - use linear motor stage, lightweight, compact
- Special optical head for BESSY
- RIKEN ELID grinding machine optical head
- In situ measurement with PTLTP at SPring8 and Taiwan
- XEUS mirror metrology proposal
- LTP II upgrades
- Develop standards for long radius measurement
- Investigate systematic error sources that prevent  $<1.0 \mu\text{rad}$  accuracy

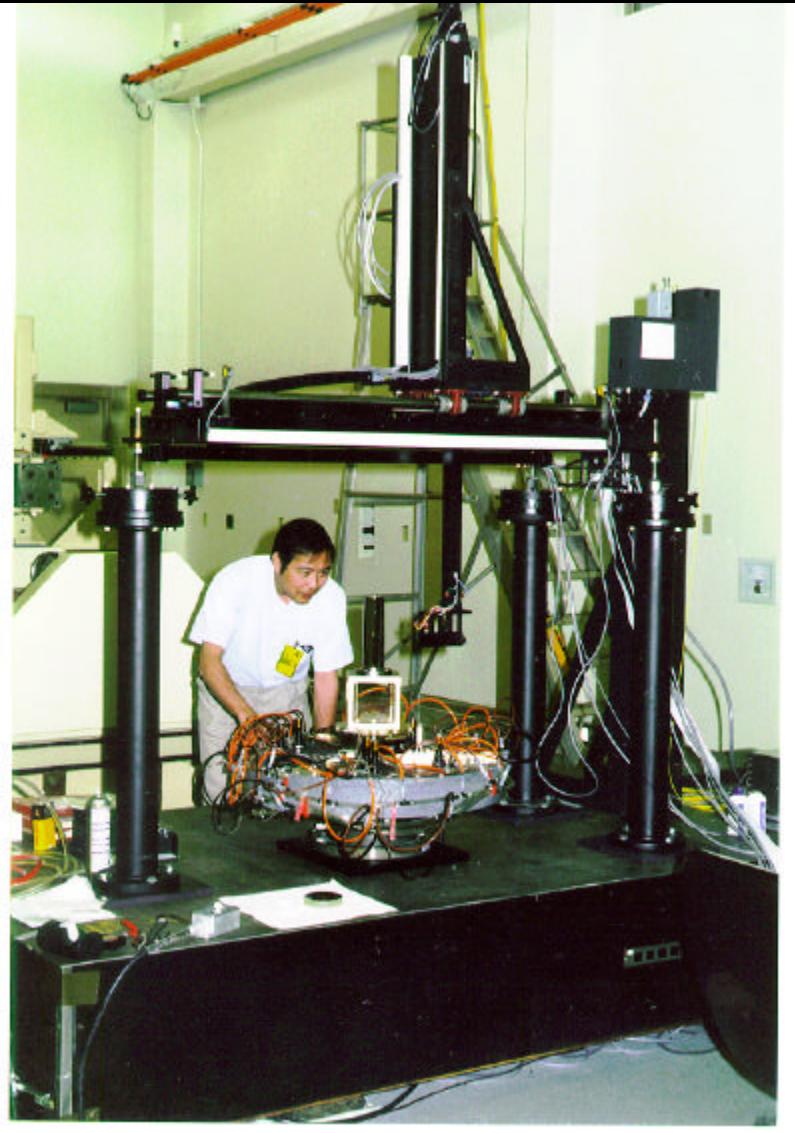
# LTP Installations Worldwide

Brookhaven National Laboratory Upton, NY USA	4	LTP I, LTP III , ISLTP, PTLTP	European Synchrotron Radiation Facility Grenoble, France	1	LTP II modified
Lawrence Berkeley Laboratory Berkeley, CA USA	1	LTP II	BESSY II Berlin, Germany	2	LTP II, LTP III
NASA Marshall Space Flight Center Huntsville, AL USA	2	LTP II, VSLTP	Synchrotron Radiation Research Center Hsinchu, Taiwan	1	LTP II
Argonne National Laboratory Argonne, IL USA	1	LTP II	SPring-8, Japan Synchrotron Radiation Research Institute, Hyogo, Japan	1	LTP II
University of Chicago Chicago, IL USA	1	LTP II	RIKEN Institute Tokyo, Japan	1	LTP III
InSynch, Inc Albuquerque, NM USA	1	LTP II	Osservatorio Astronomico di Brera Merate, Italy	1	LTP II
Ocean Optics, Inc. Winter Park, FL USA	1	LTP IV	Pohang Accelerator Laboratory Pohang, Korea	1	LTP II
Sincrotrone Trieste Trieste, Italy	2	PTLTP, ISLTP	Crystal Scientific Alnwick, England	1	LTP II *

# VSLTP at NASA MSFC

- X-ray telescope cylinders and mandrels to 1 m diameter
- SBIR with Continental Optical, design by T. Oversluizen



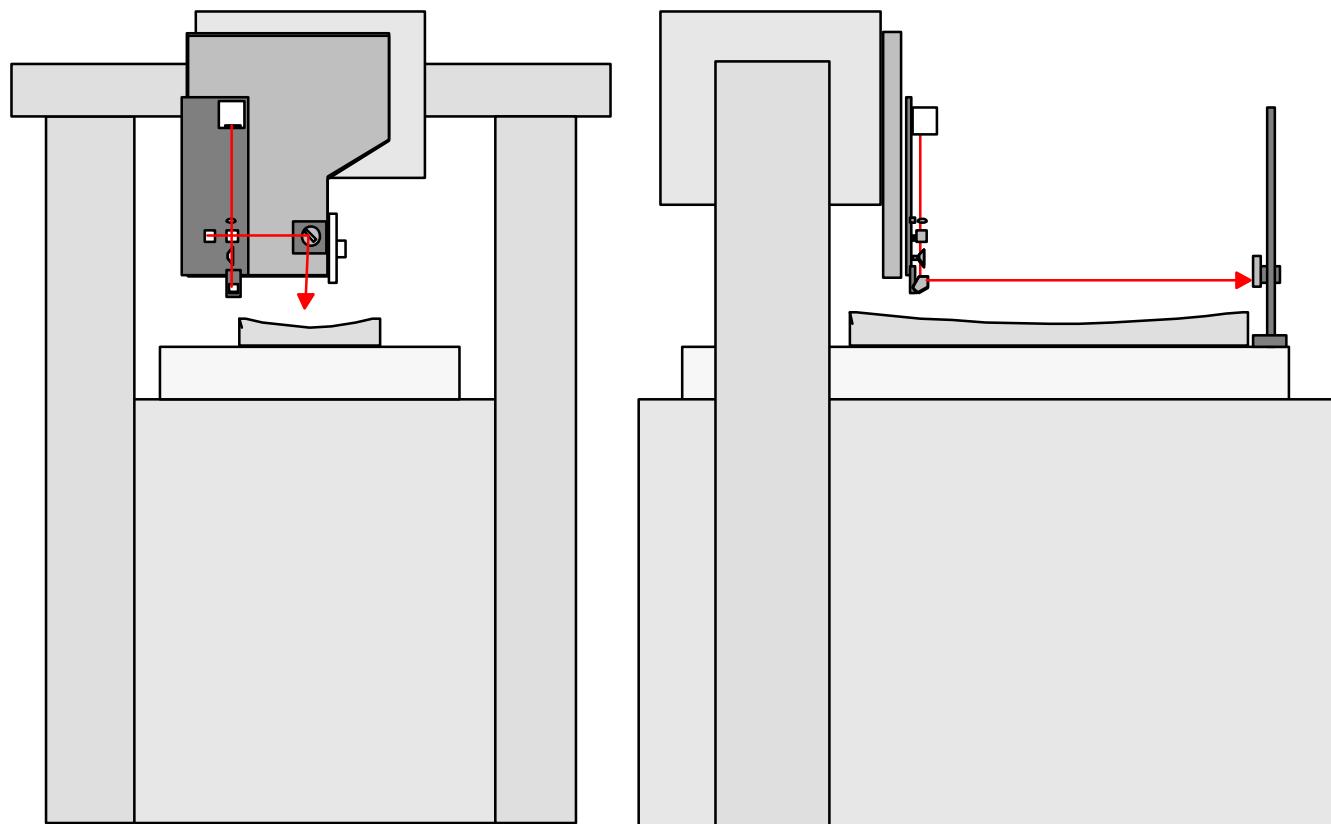


# RIKEN ELID Optical Head

- ELID ultra precision grinding machine
  - “electrolytic in-process dressing” of cutting tool
  - produces ready-to-polish cylindrical optics in glass, Si, SiC
- Need for on-machine metrology for final fabrication stages
- Collaboration with BNL (design, optics board) and Ocean Optics (fabrication, detector, software)
- Interface ContOpt software with ELID motion control system
  - field installation by OOI software engineer
- Added 3D surface map capability with beam-steering mirror
- Problem with cylinder lens installation - rework system

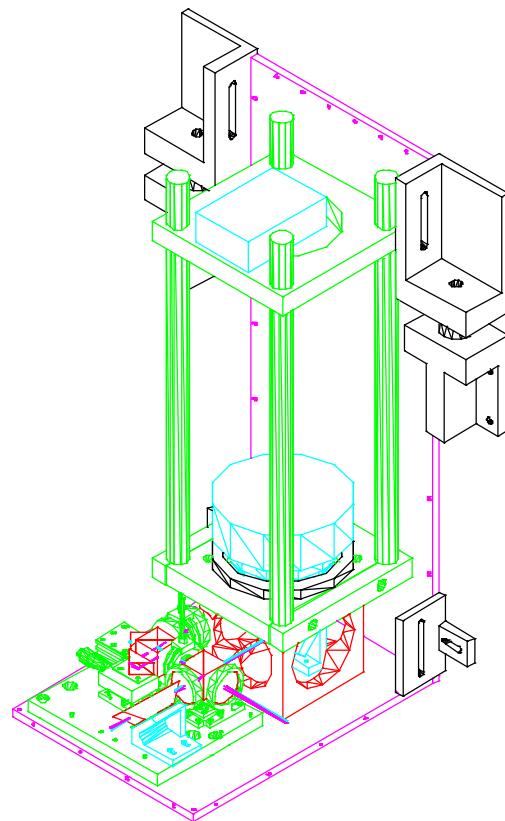
# ELID Ultra Precision Grinding Machine

Sketch with LTP optical head installed

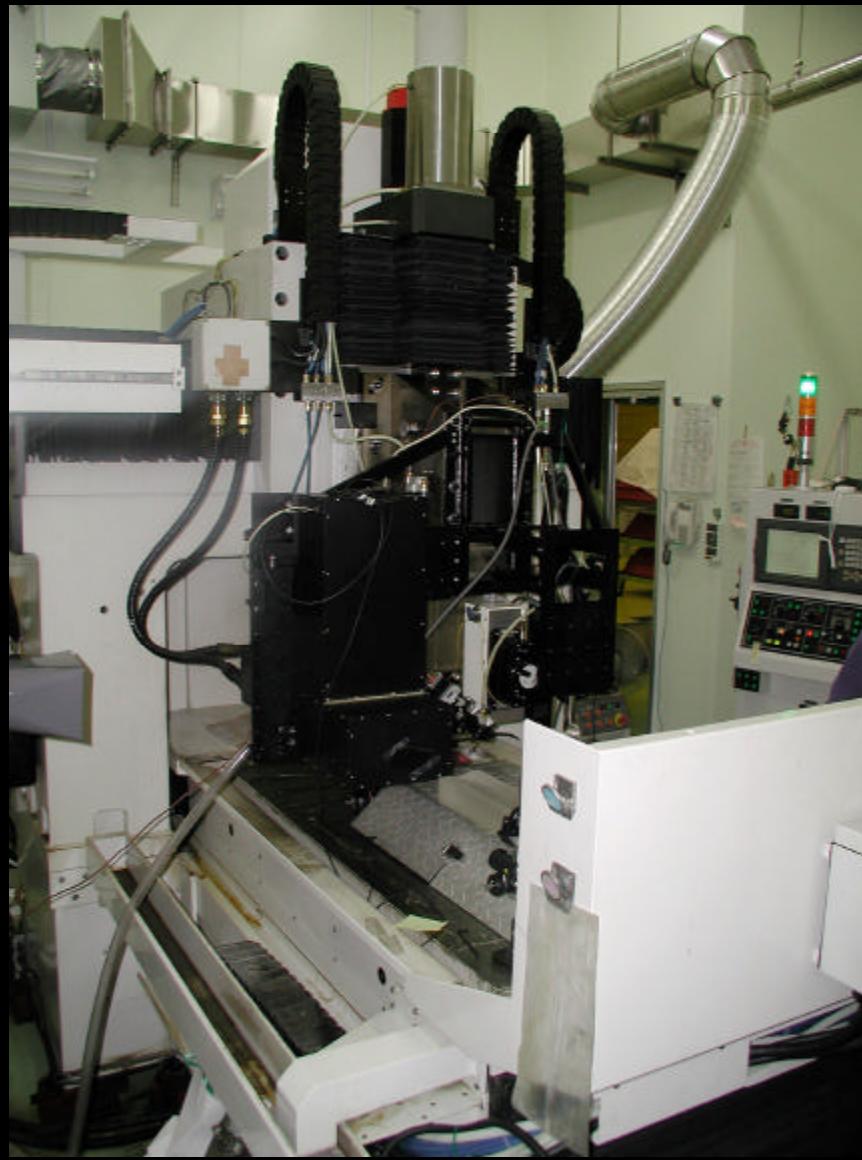


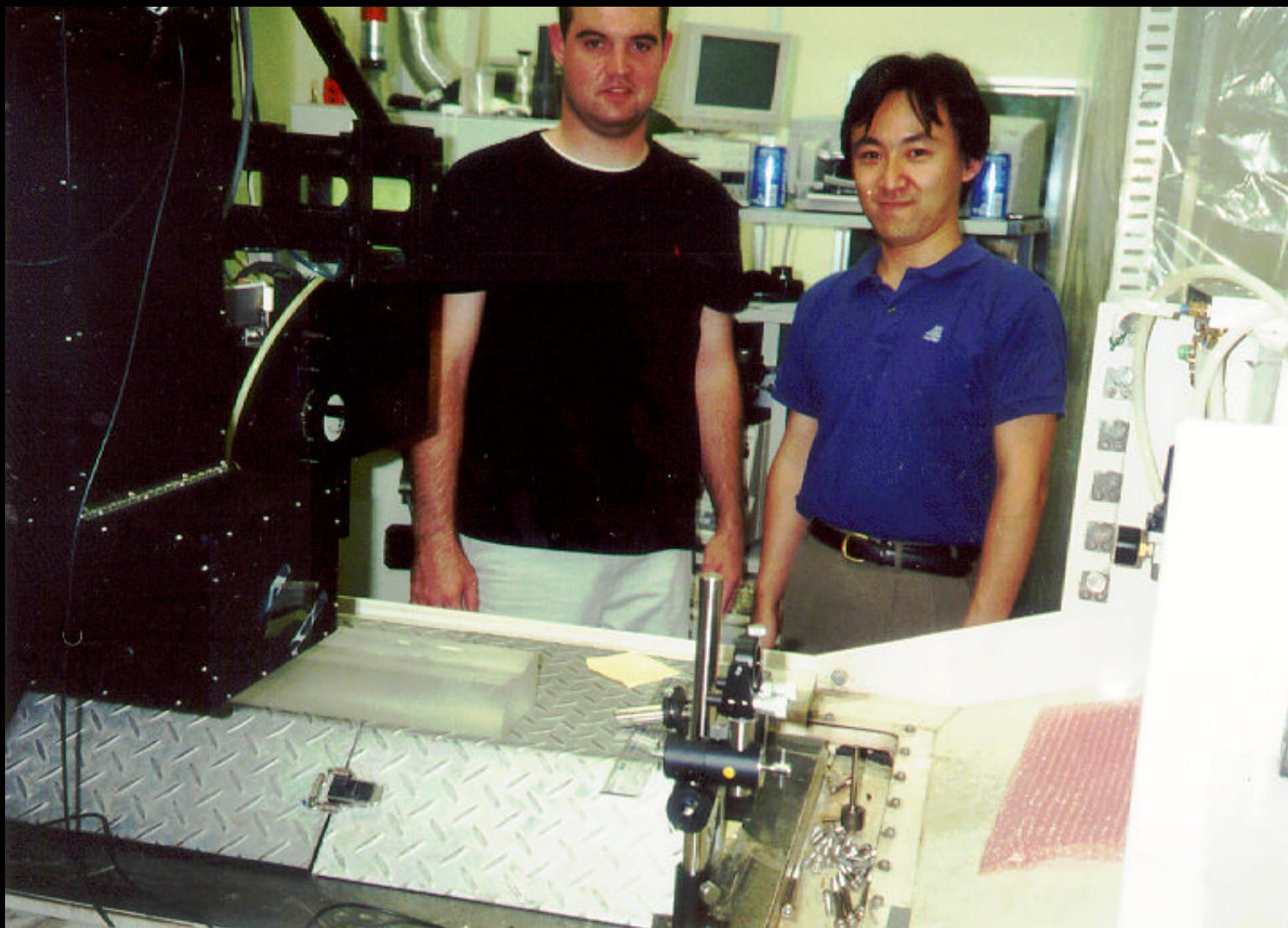
# ELID LTP Optical Head

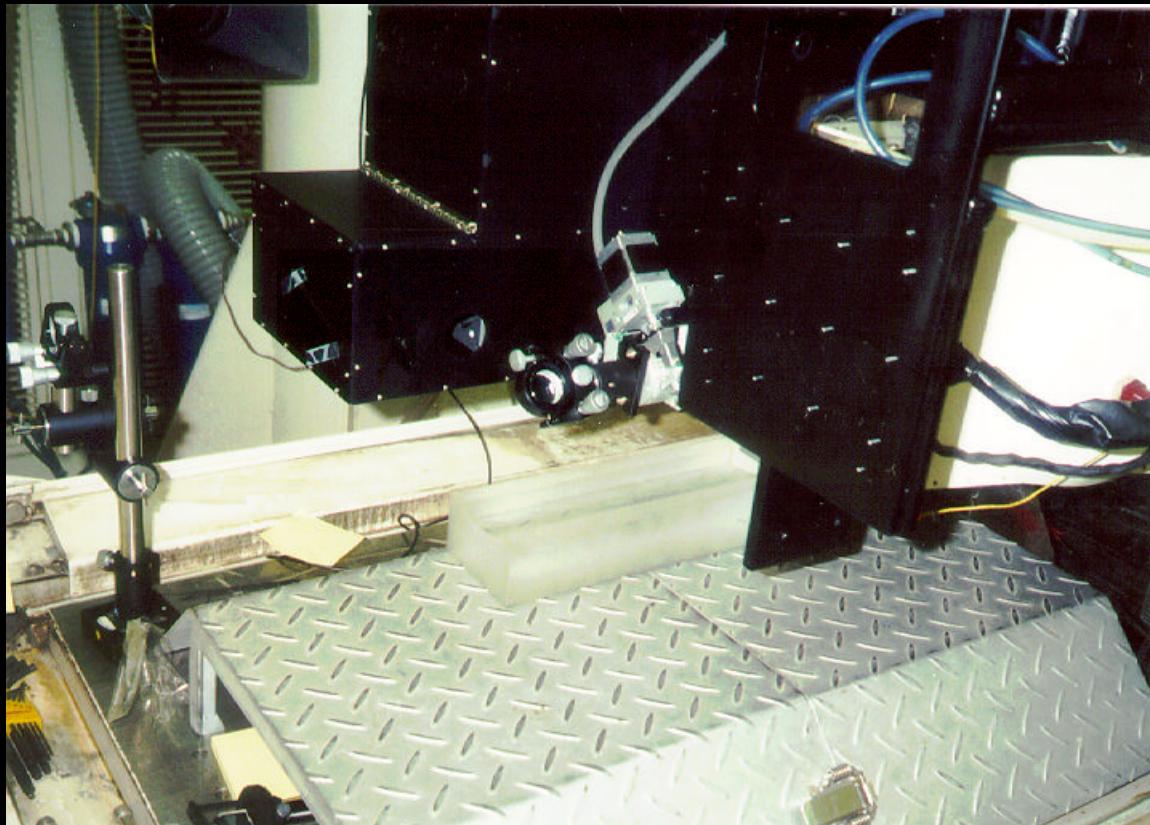
- Uses existing optics board
- **Off-the-shelf** parts for lens bench
- Incorporates OOI detector



Kinematic mount for  
installation on machine



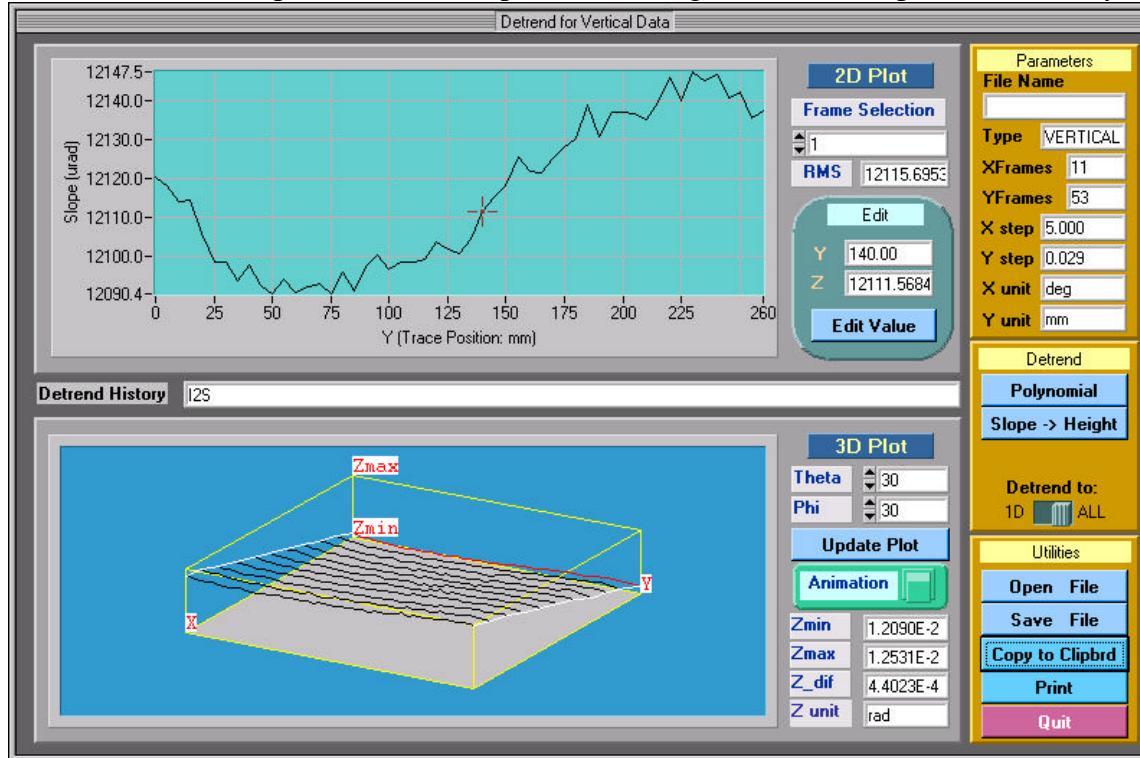




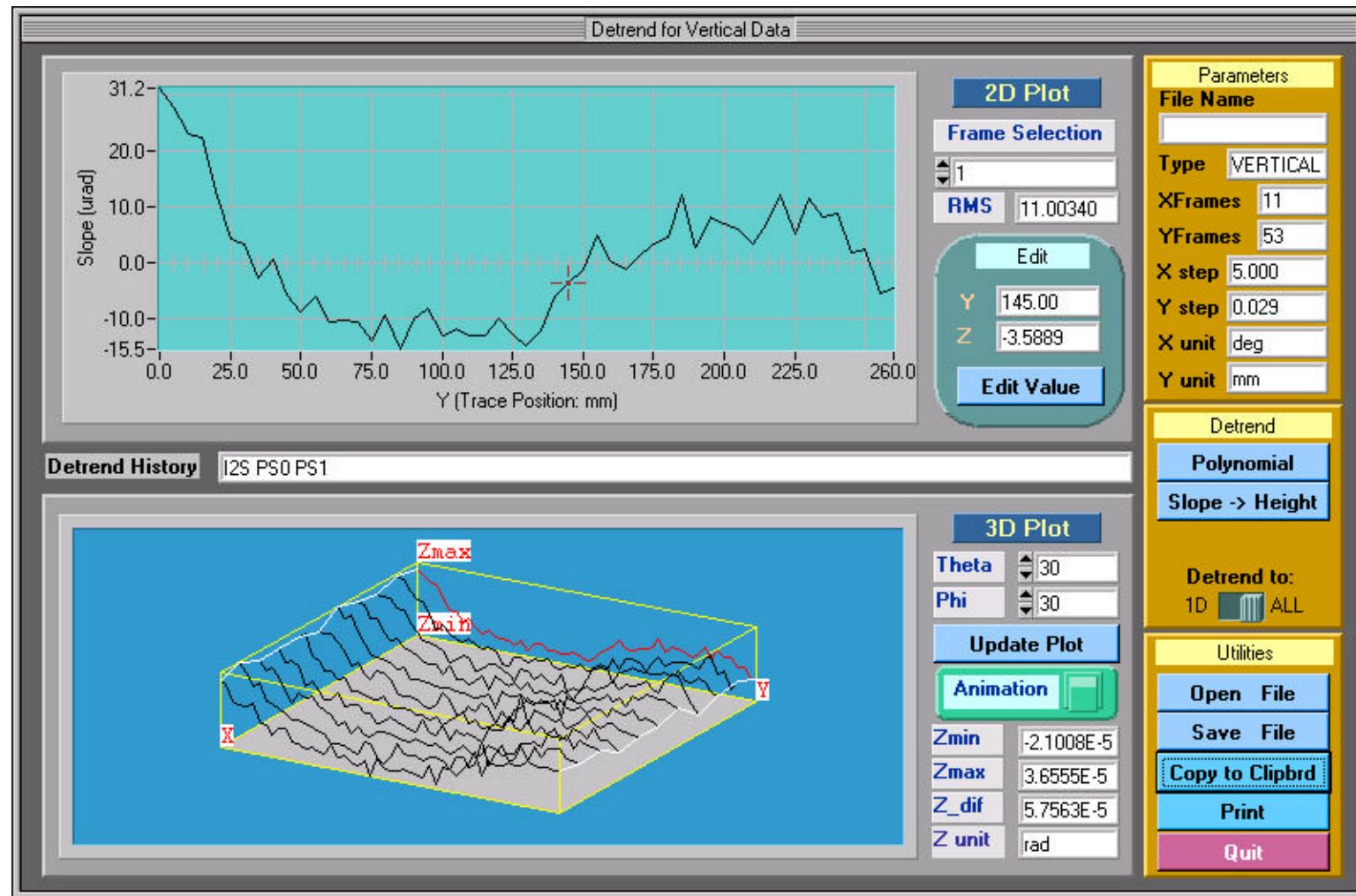
# ELID LTP Data

## Analysis code based on VSLTP 3D surface analysis

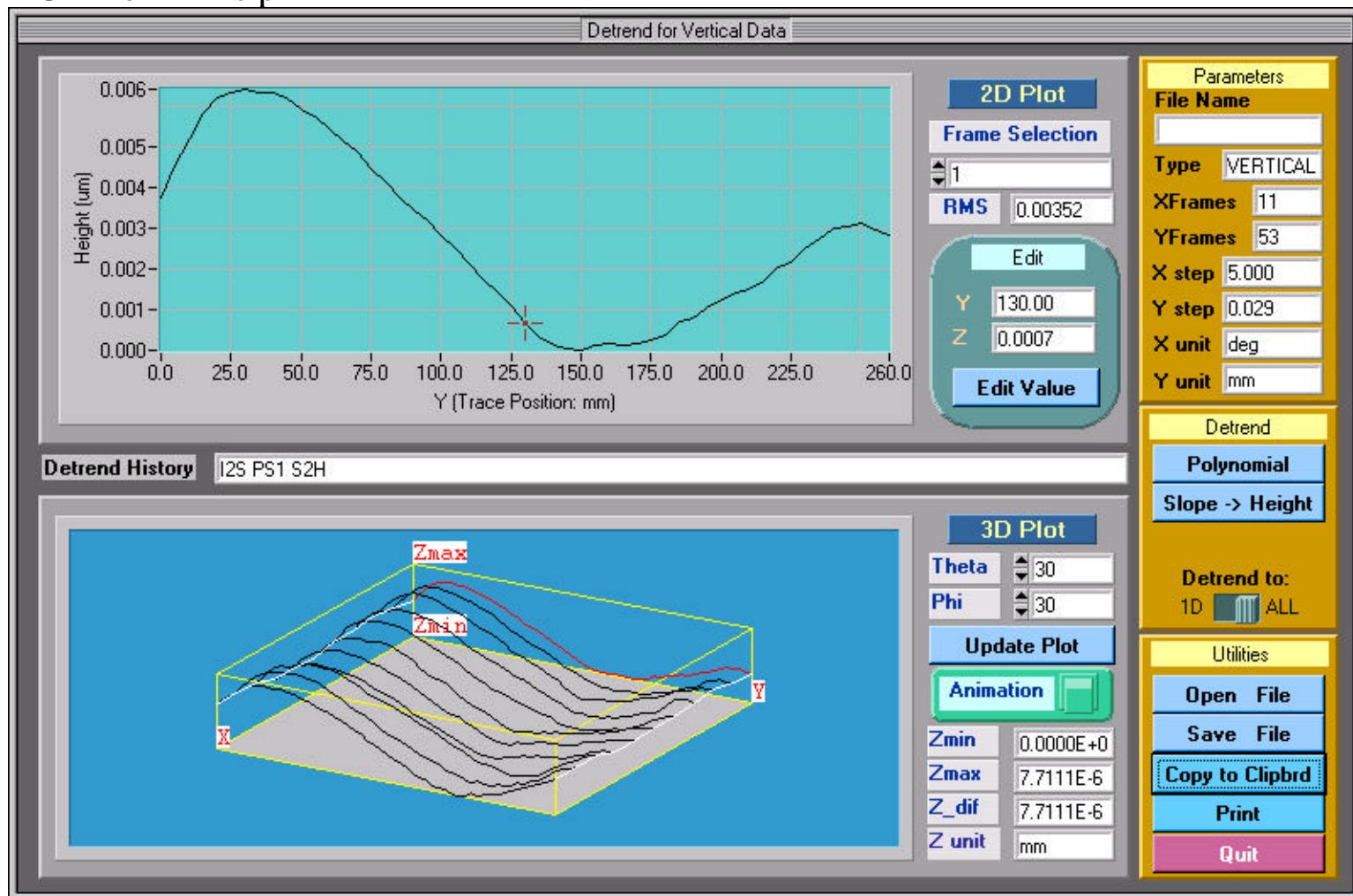
CYL11.raw - fix W parameter to compute correct angle. Now scan up full width of cyl.



# D1 SLP

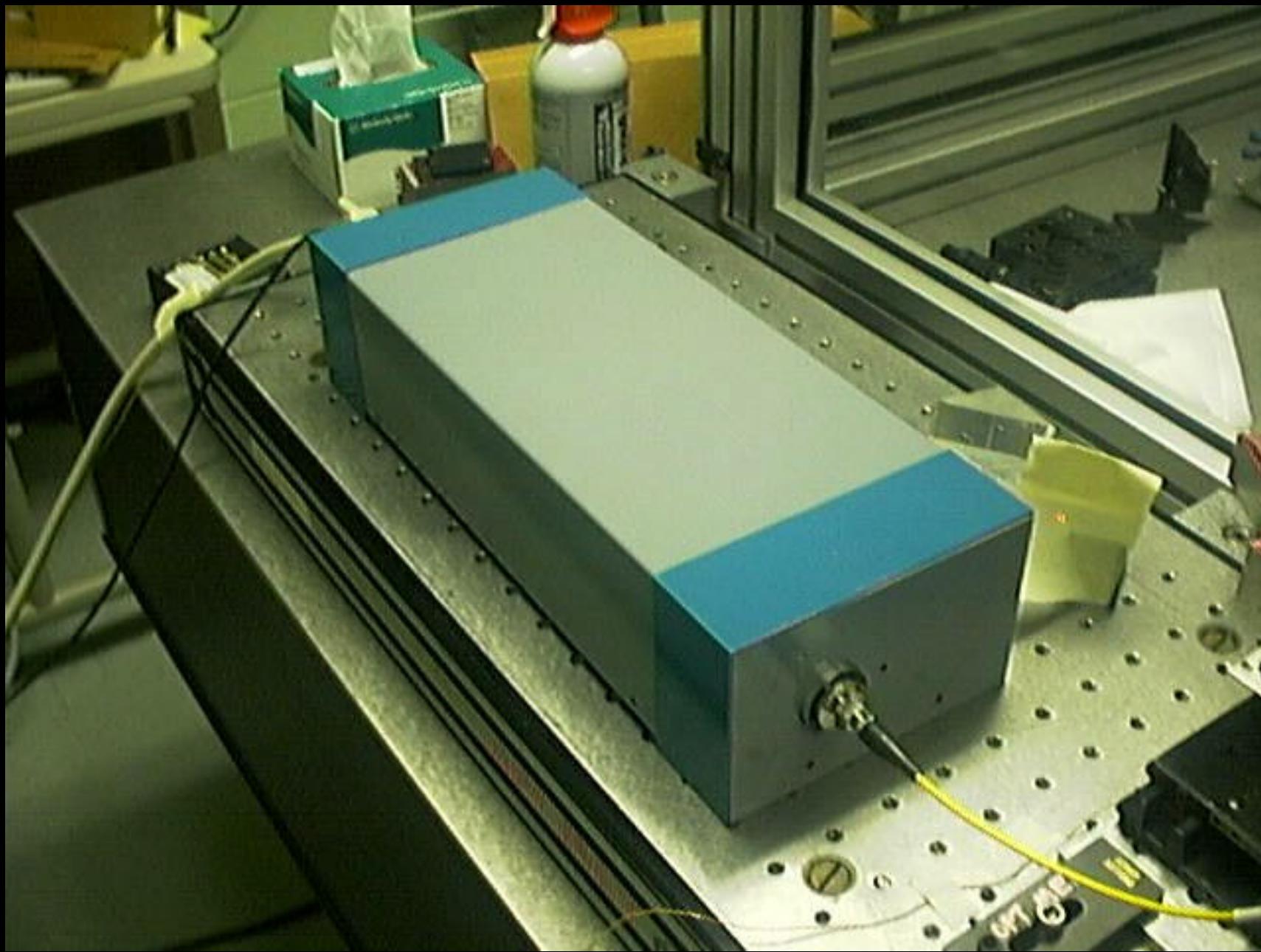


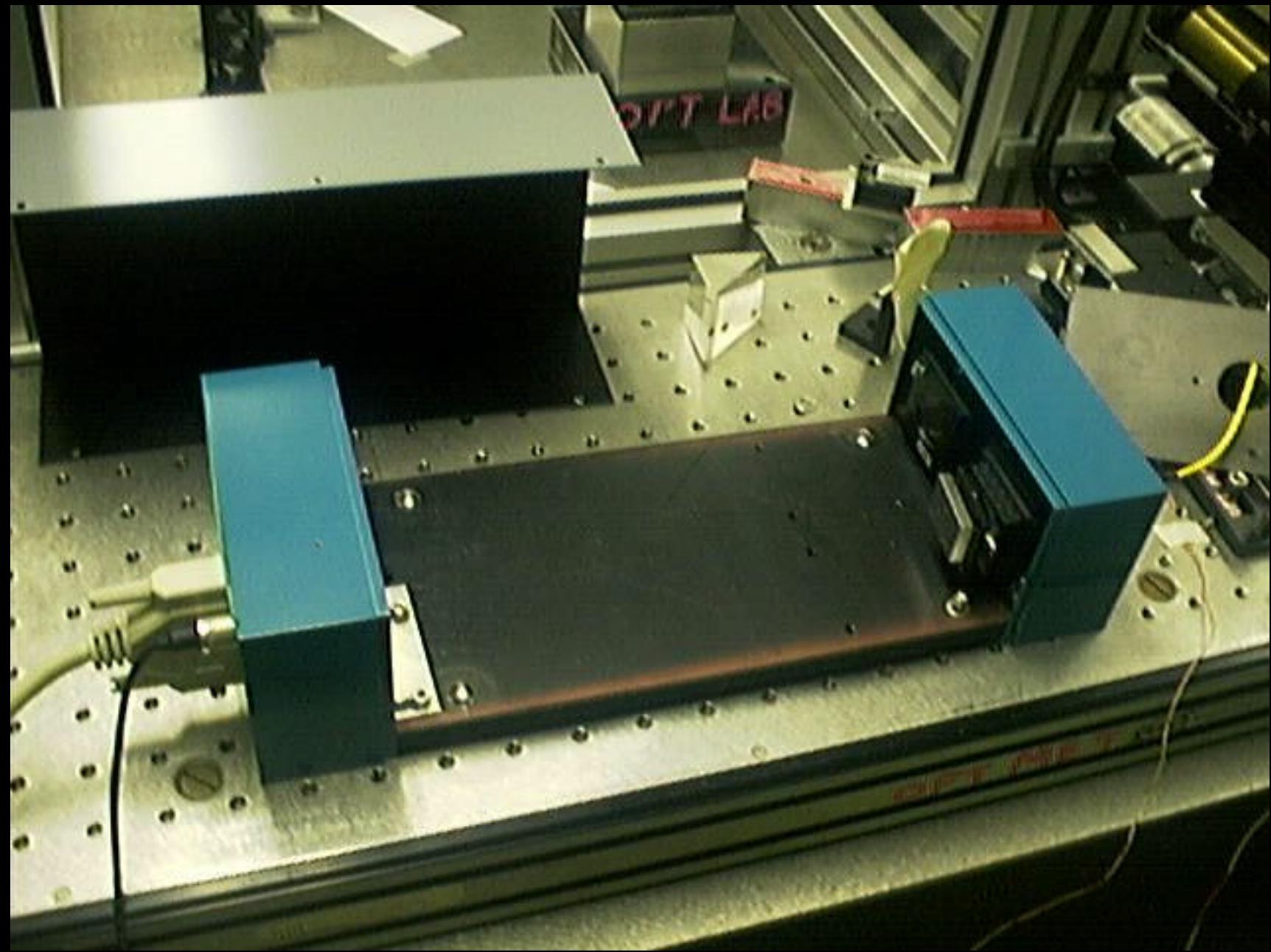
# HGT from D1 slp



## Portable LTP - PTLTP

- Compact optical head design
- Uses monolithic SBS beamsplitter for exceptional stability
- Basis for current Ocean Optics standard unit
- Use for *in situ* measurements of mirrors under actual operating conditions
- Designed for “before-after” measurements, not for absolute accuracy
- Collaboration with SPring8 - distortion of cooled grating in soft x-ray beam line
- Adaptable to different translation stages



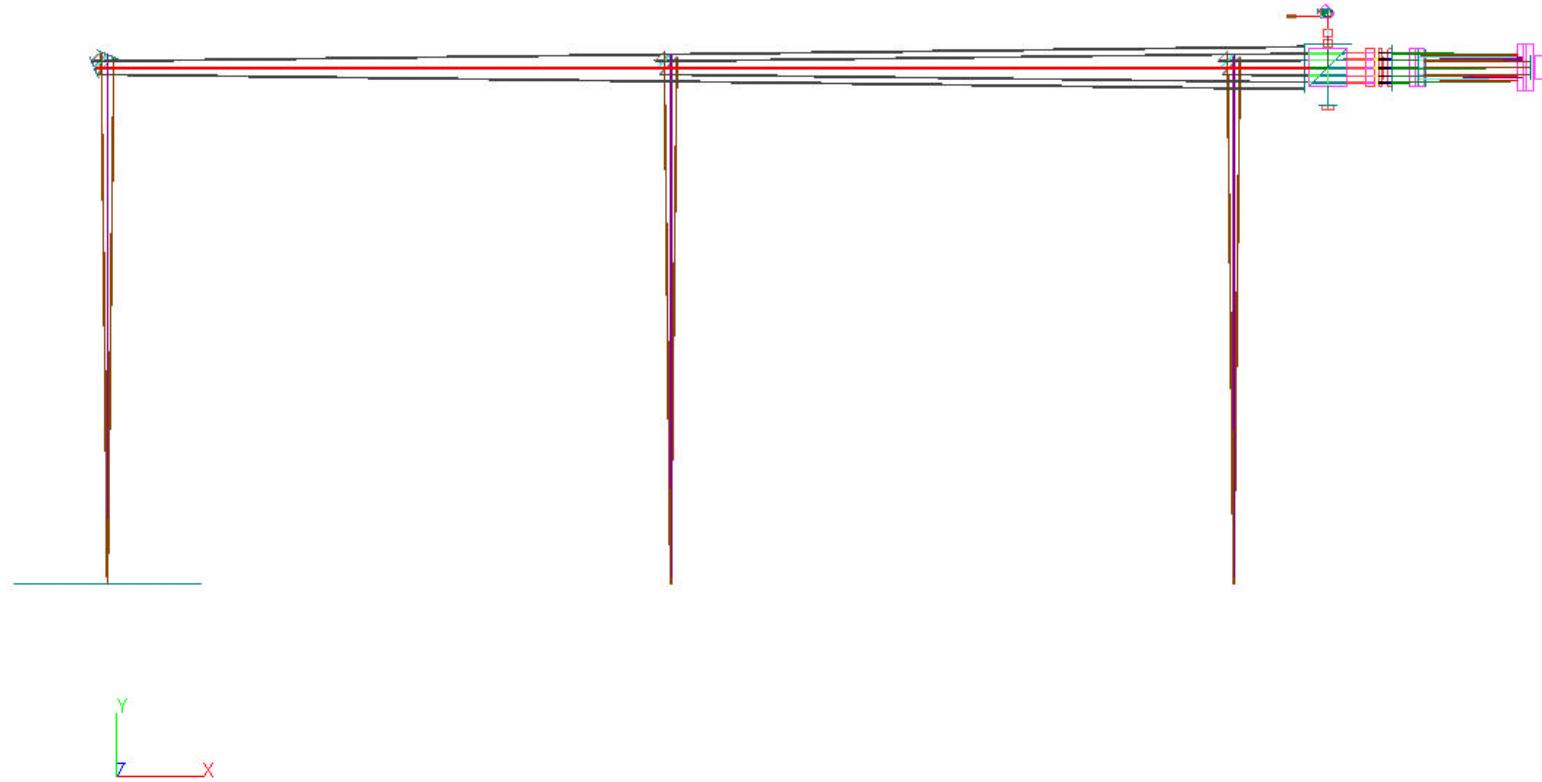


# BESSY Optical Head

- For German NOK project (Nanometer Optikkomponenten)
  - Optical head for ultra-precision metrology of optics for x-ray lithography
- Requirement for **10nm absolute accuracy** over 1.2 meter length.
- Need **<30nrad slope error accuracy**
  - Stringent performance on lens design
  - Low distortion F-θ lens
- Model various configurations with **ZEMAX** and **OptiCAD**
  - Moving optical head -> better lens performance
  - Fixed optical head, penta prism scan -> less mechanical error

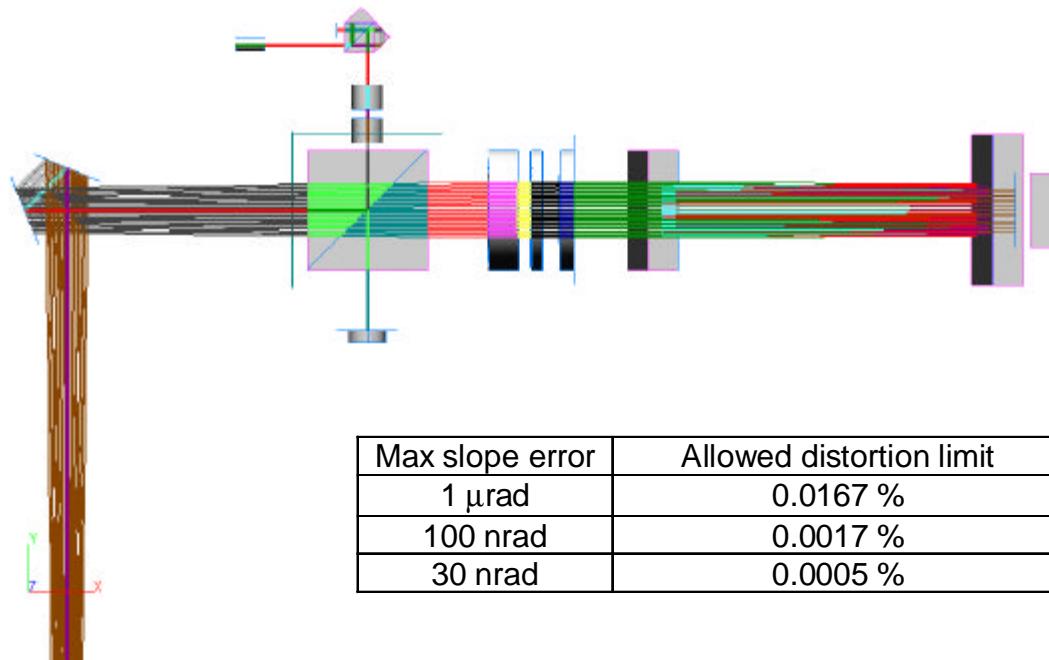
# BESSY Optical Head Design

- Scanning penta prism, fixed optical head  
-> difficult lens problem
- 3 SUT ranges: 1750mm, 1150mm, 550mm
- Max surface angle:  $\pm 6.6\text{mrad}$
- Minimize distortion over all ranges and angles



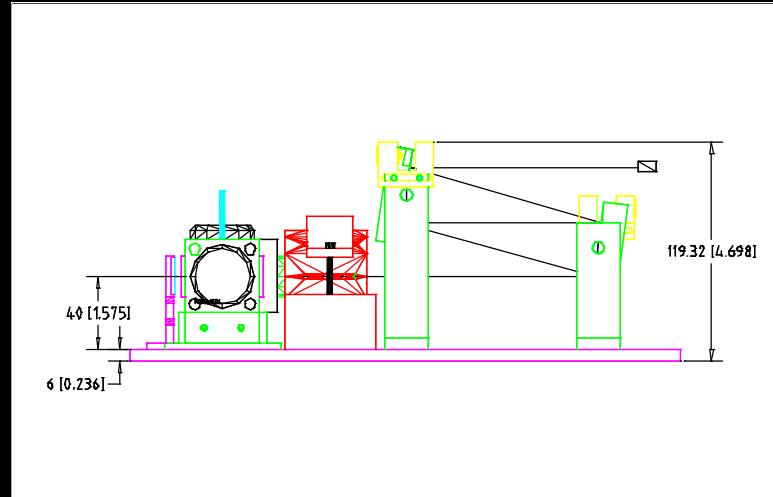
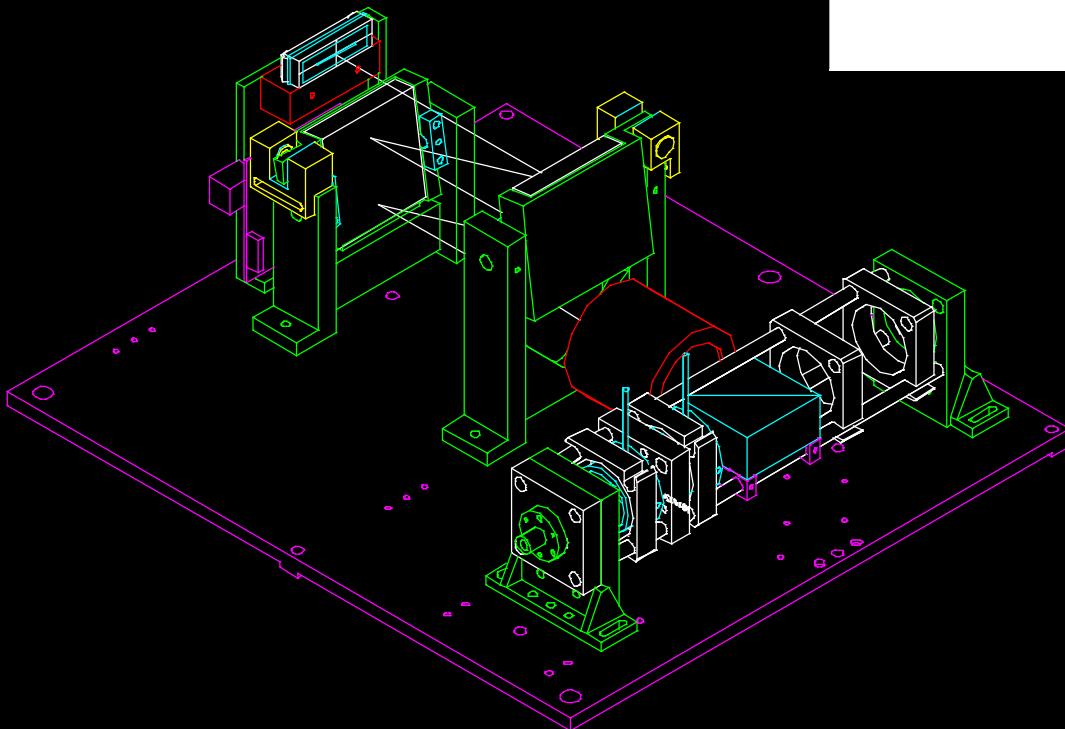
# OptiCAD Raytrace of BESSY LTP

- Fixed optical head, moving penta prism
- 3 element lens design gives 100nrad performance
- Fixed head requires larger size optics -> more errors
- Moving head design - can get <2nrad distortion



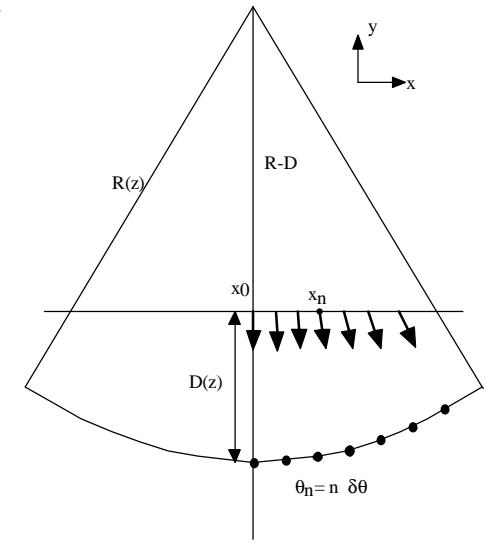
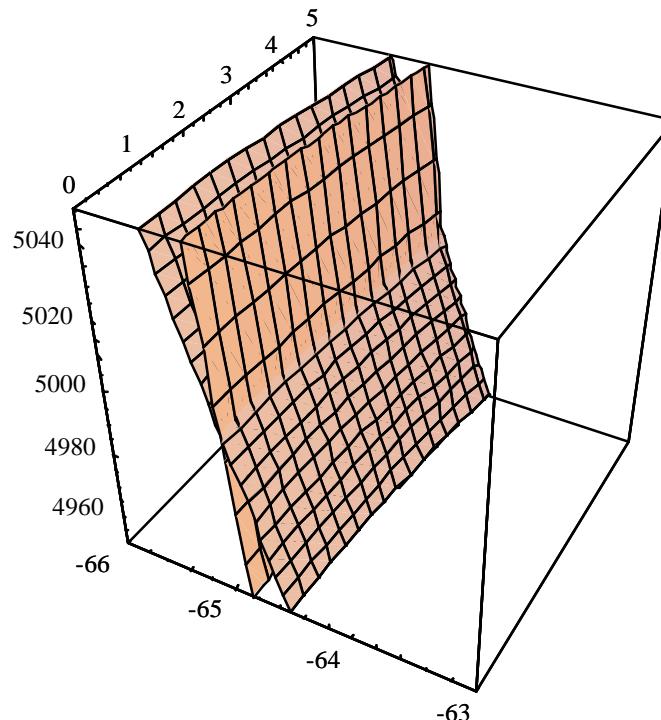
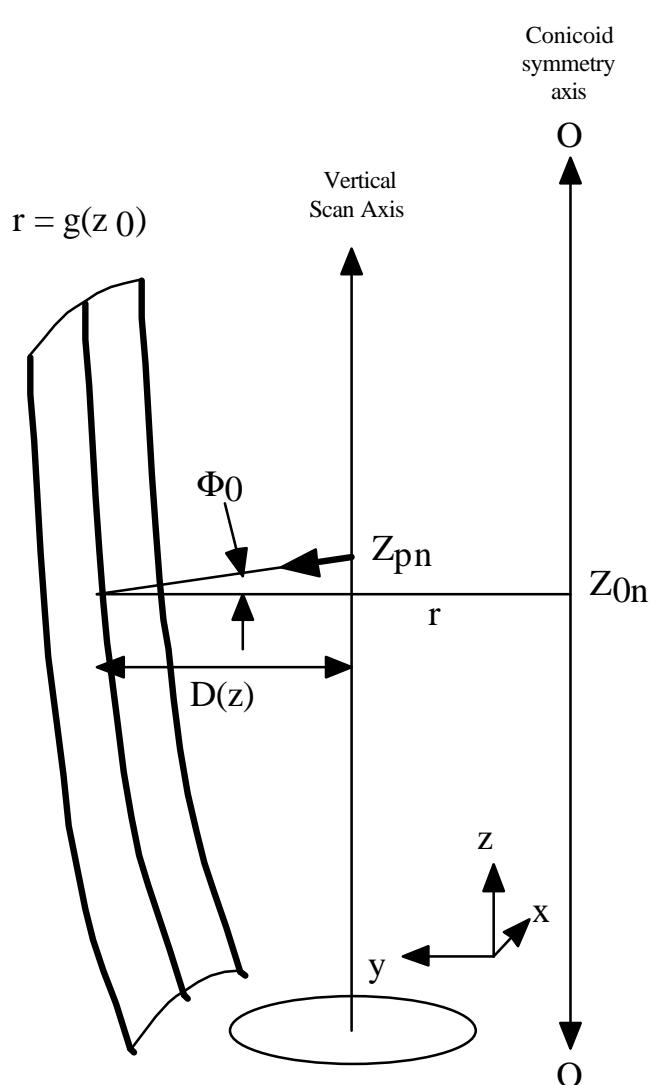
# BESSY LTP

## Uses Microbench parts



# XEUS X-ray Telescope Metrology

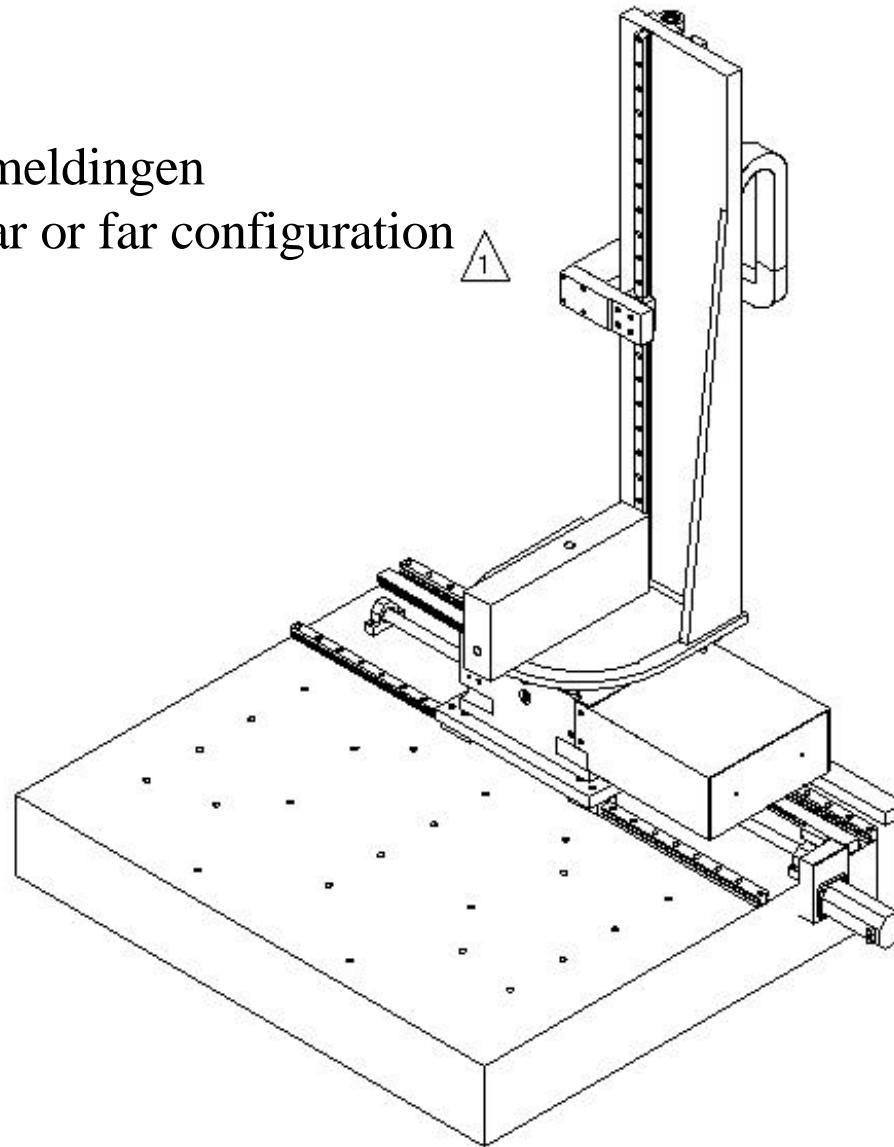
- Collaboration with O. Citterio at Osservatorio Astronomico di Brera, Milano, Eimeldingen, OOI
- Measure Wolter telescope segments: 1.2 to **10 meters** in diameter
- Nested thin foil segments, 1m x 1m square, vertical orientation
- Scan up from table top, not down from bridge structure
  - more compact system
- Scan close to surface or along symmetry axis???
- Require 100 nm accuracy with 3D full-surface map
- Difficulty is azimuthal scan accuracy
  - requires including mechanical tolerances in measurement loop.
- Proposal due later in 2002



3 axis stage by Eimeldingen

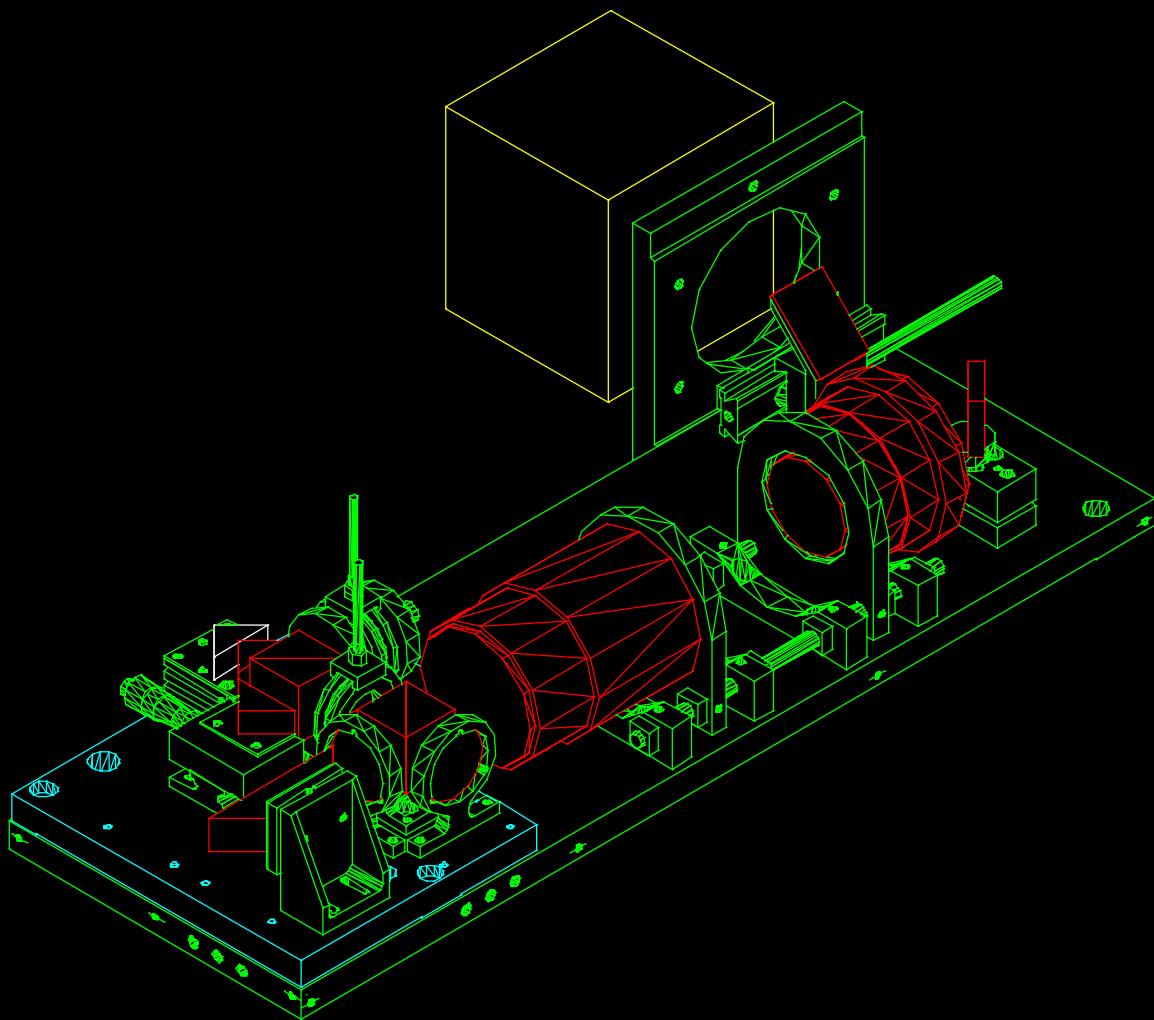
Can be used in near or far configuration

1



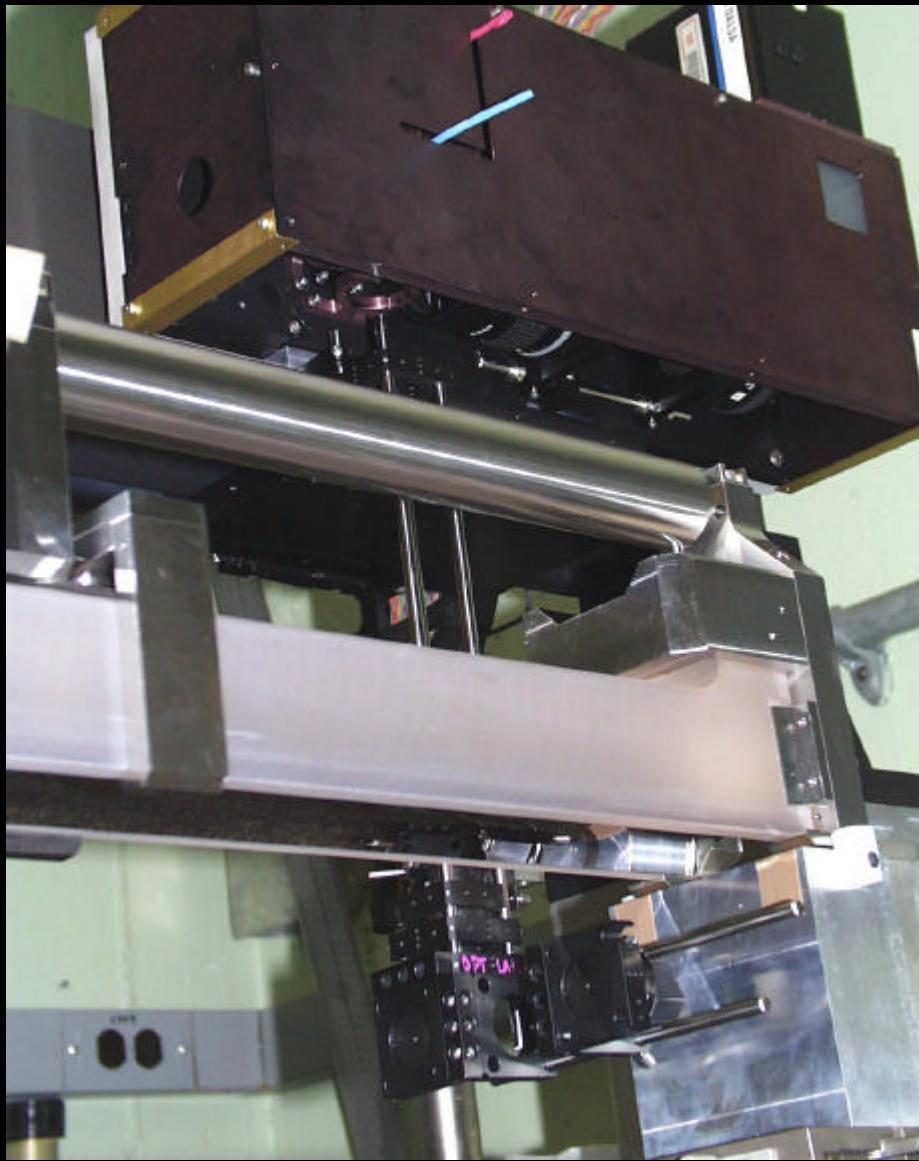
# LTP III

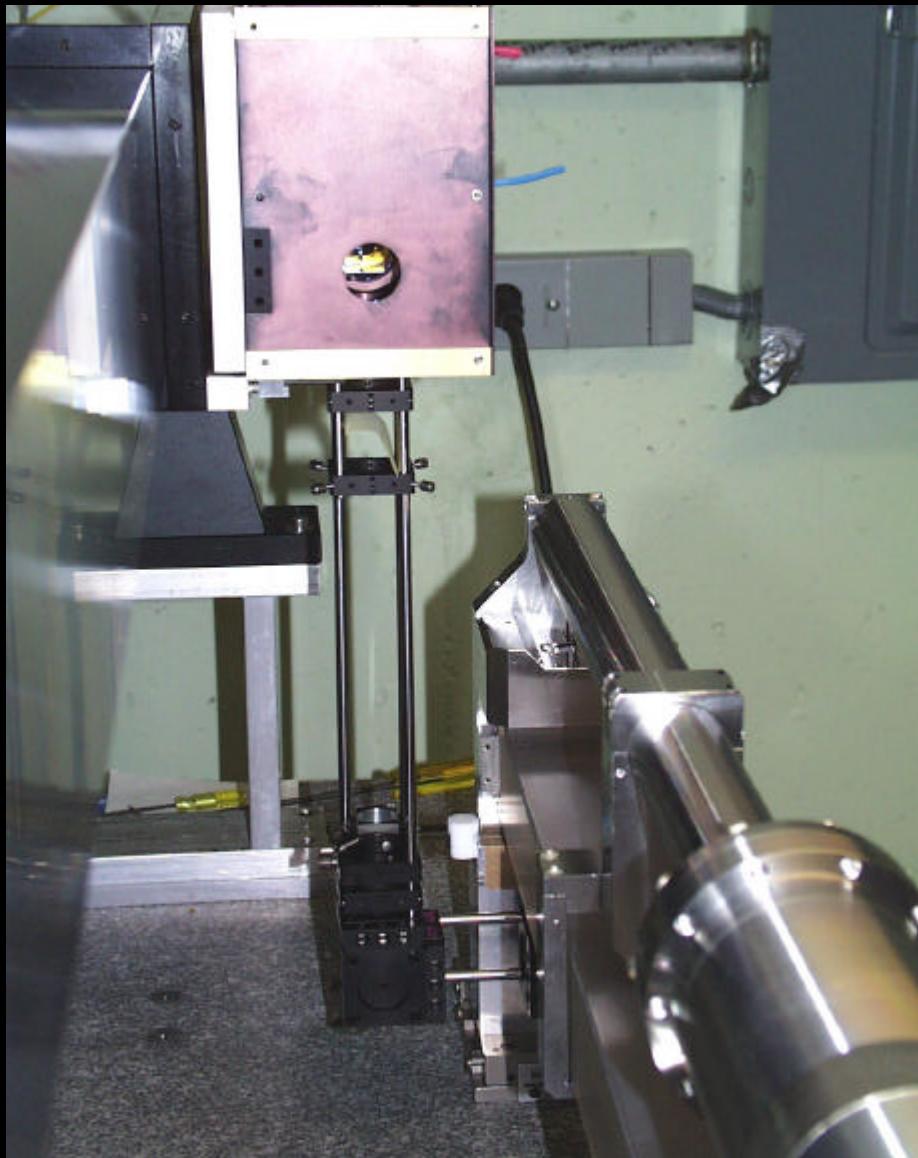
- Replaced original LTP I in Metrology Lab
- Dalsa camera, frame grabber, Nikon lenses, same GPIB motor controller
- LabVIEW control and analysis program
- Versatile, custom configuration for any mirror geometry
  - Face up, face down, sideways
- Thermal sensitivity
  - Replace NBS with SBS or phase plate
- Systematic errors at the microradian level

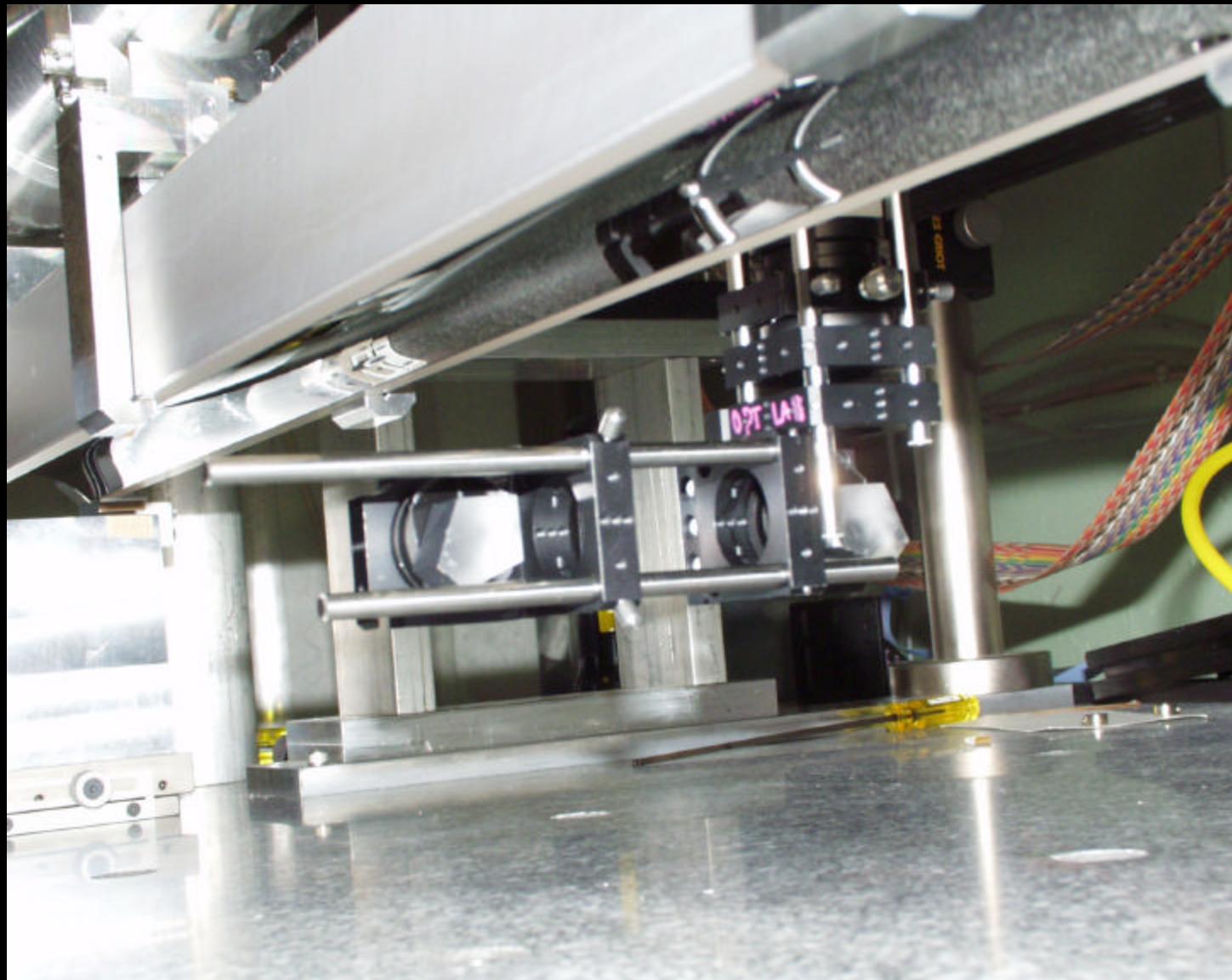


X12B - SESO cylinder mirror, face down

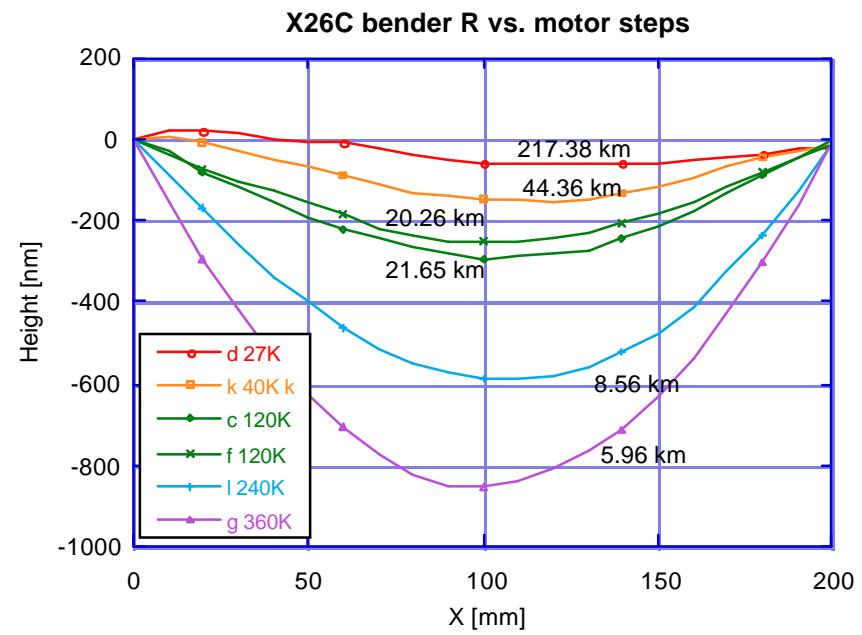
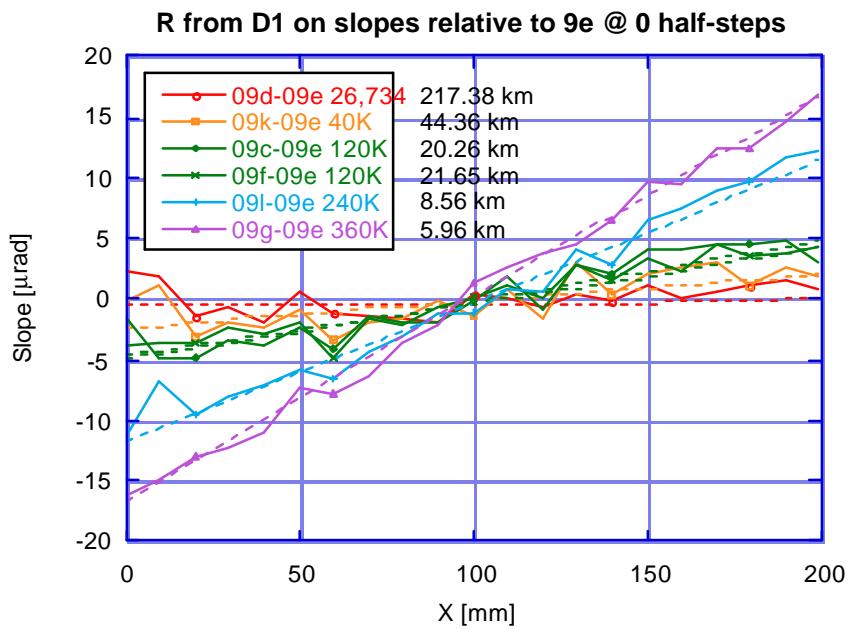








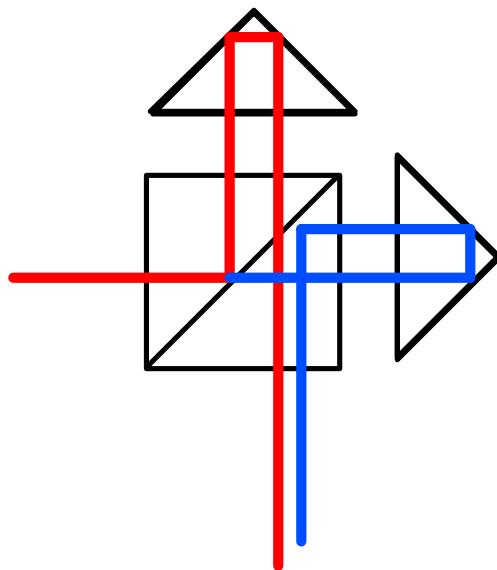
# X26C Mirror bender calibration



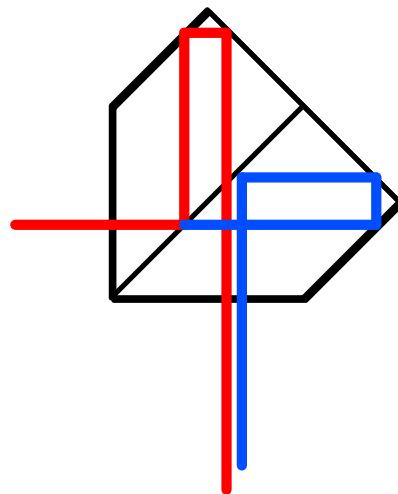
# Stability vs. Beam-splitting Optics

Produce phase shift of  $\lambda/2$  between beams

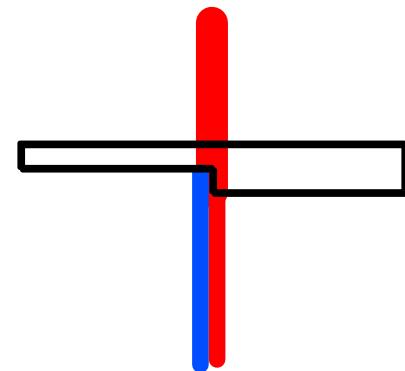
NBS w/Porro prisms  
(separate pieces)



SBS  
(monolithic)



Phase Plate



Standard LTP

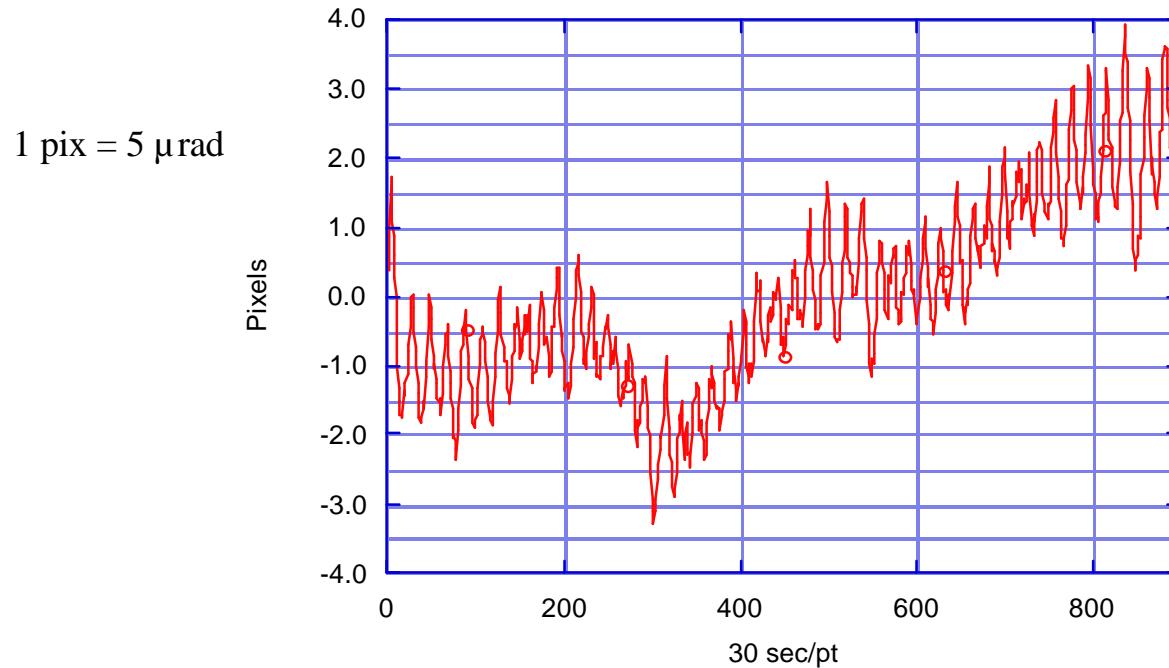
Compact LTP  
Qian patent pending

Z. Li, et al  
Tsinghua University

# LTP III Stability Scan - 7 hours

BNL LTP III optical head with  $\Delta T=0.2^\circ\text{C}$

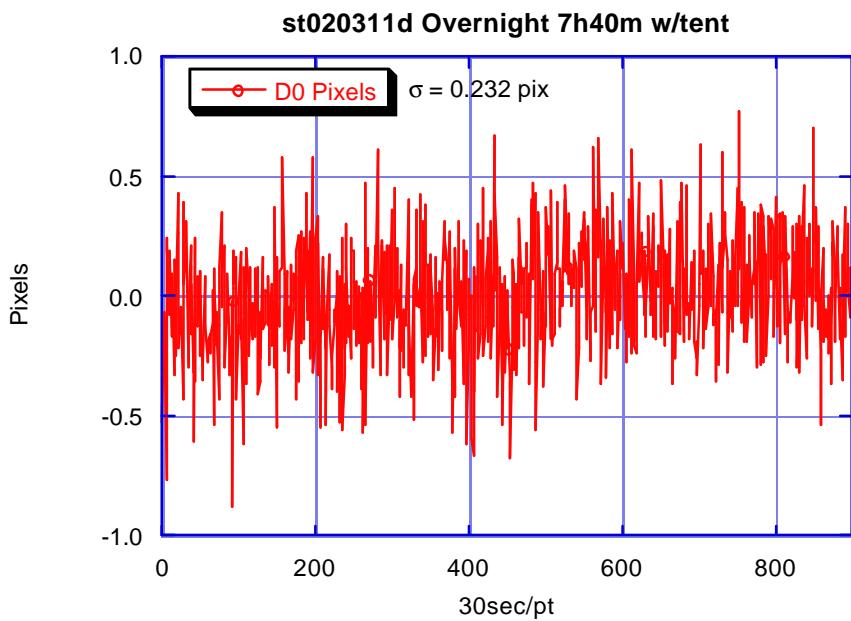
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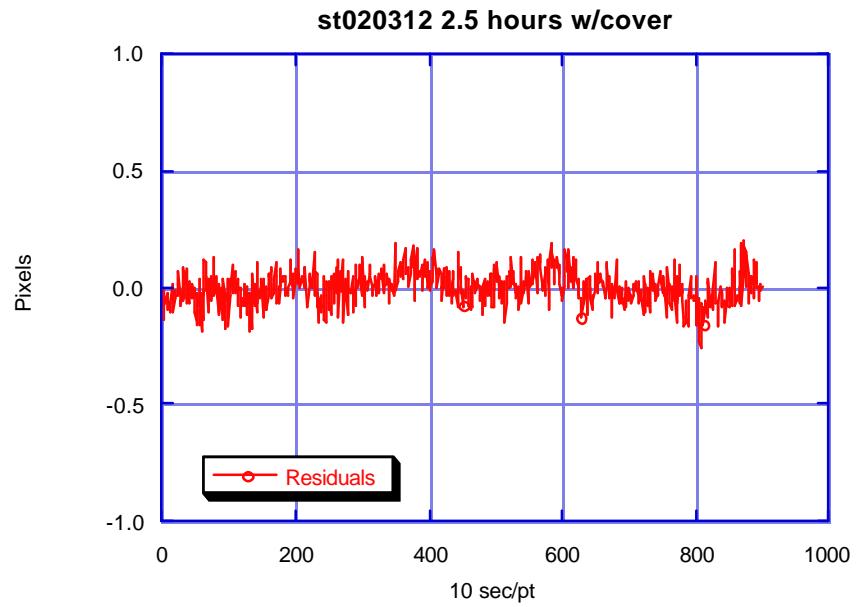
Very sensitive to temperature and humidity fluctuations.

# Improve BNL LTP III Stability

Using SBS monolithic beamsplitter



Using phase plate

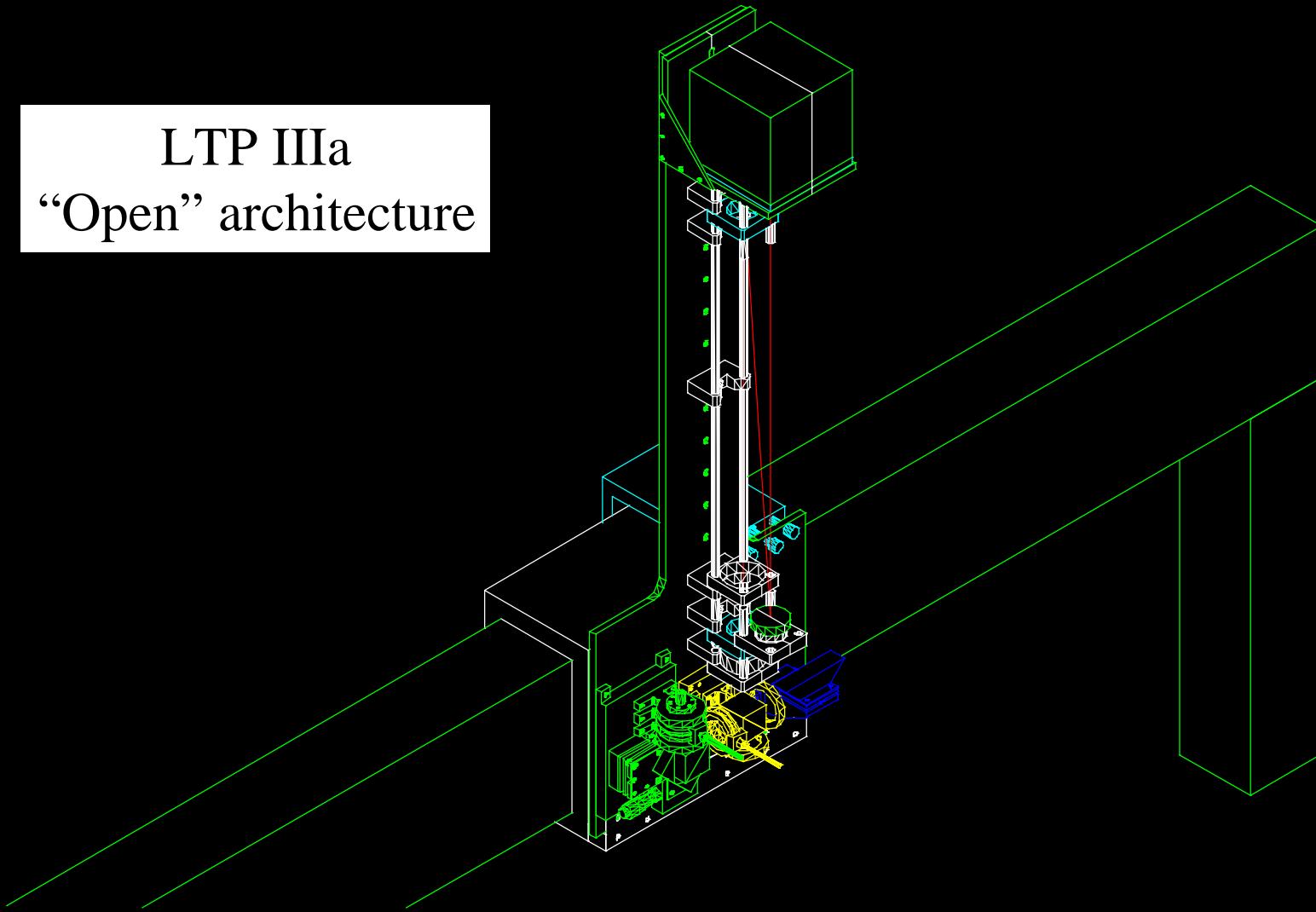


# Systematic error effects

- Difficult to achieve accuracy below 1  $\mu$ rad in LTP III
- Lack of repeatability in long-radius measurements
- Suspect glass inhomogeneity problems in lenses and PBS
- Modify LTP III structure to “open architecture” system -  
    => **LTPIIIa**
  - Use of Microbench parts
  - Allows for rapid reconfiguration
- Use external laser source for LTPIIIa tests

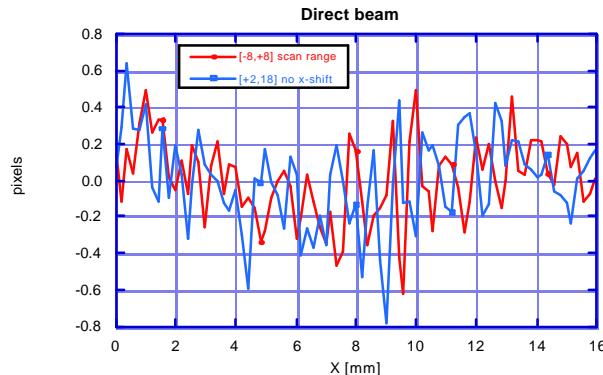
# LTP IIIa

## “Open” architecture

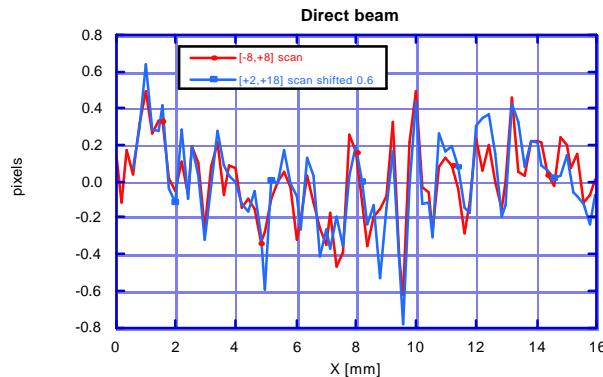


# LTPIIIa w/External Laser - Single Direct Beam

- Remove all glass between laser and detector.
- Scan carriage at 0.2 mm steps.
- Shift absolute position by ~10mm between scans.
- 2nd order polynomial fit to peak of Gaussian beam.



2 sets of scans, average of 16 scans in each set.



Shift second scan by 0.6mm to align starting points

# External laser test - results

- See microradian-level errors in residuals between adjacent points.
- Independent of measurement location of carriage
  - Not caused by encoder position error or lead screw error
- Must be internal to Dalsa detector chip?
- Multiple reflections in cover glass?
- Investigate effect of smaller beam size.
- Possible solutions-
  - Lookup table for position correction
  - Replace Dalsa camera with OOI USB detector.
    - Requires major software change to C++ code.
    - Change motor controller

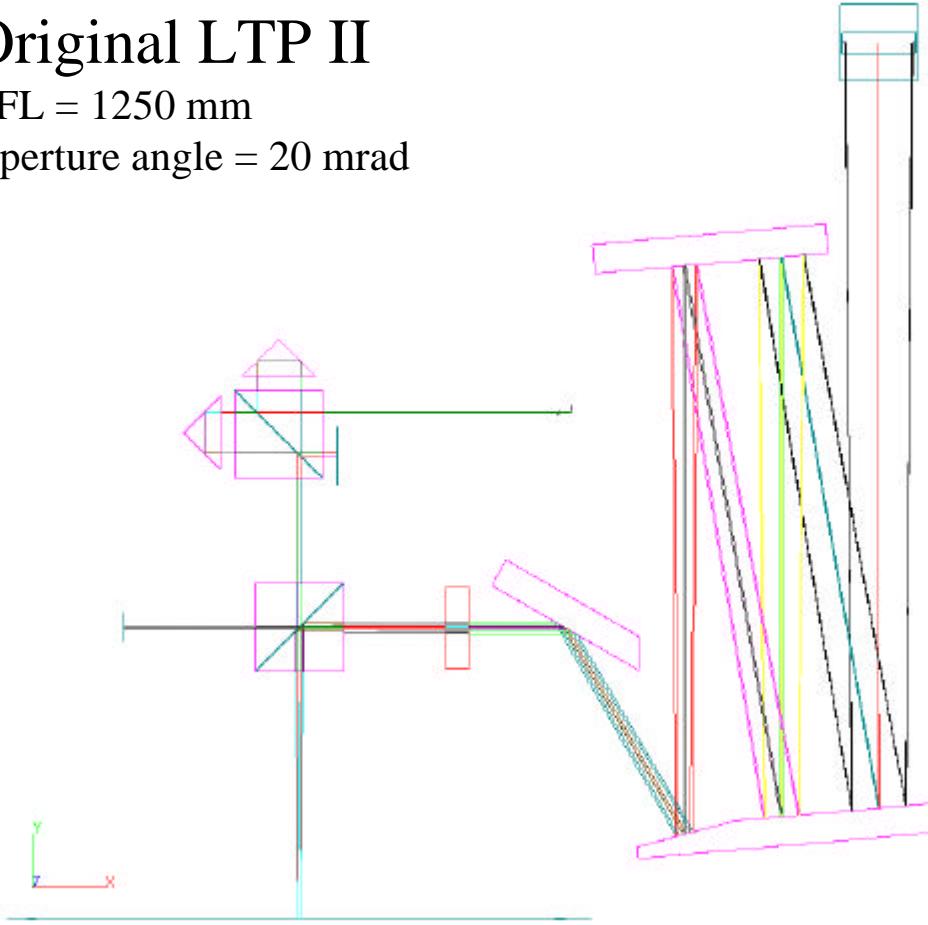
# LTP II upgrades

- Original Princeton Instruments detector obsolete - dual array no longer made by Reticon
- ISA bus interfaces for detector and motor controller obsolete
- USB interface with OOI detector, motor controller
- Increase surface slope range from 10 mrad to 30 or 60 mrad
- Requires decrease in focal length and change in folding mirror board
- Design criteria
  - Keep detector in current location
  - Keep current PBS aperture - 30mm
  - Single lens and single folding mirror
- What range of acceptance angles are possible with current geometry?

# Original LTP II

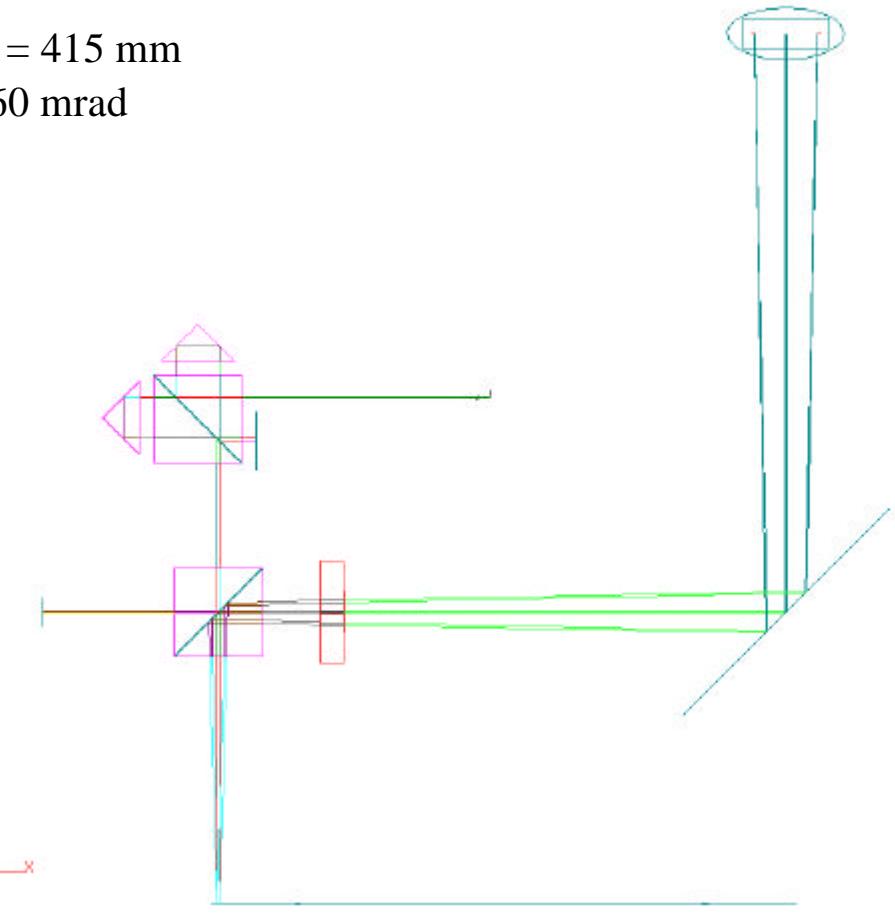
EFL = 1250 mm

Aperture angle = 20 mrad



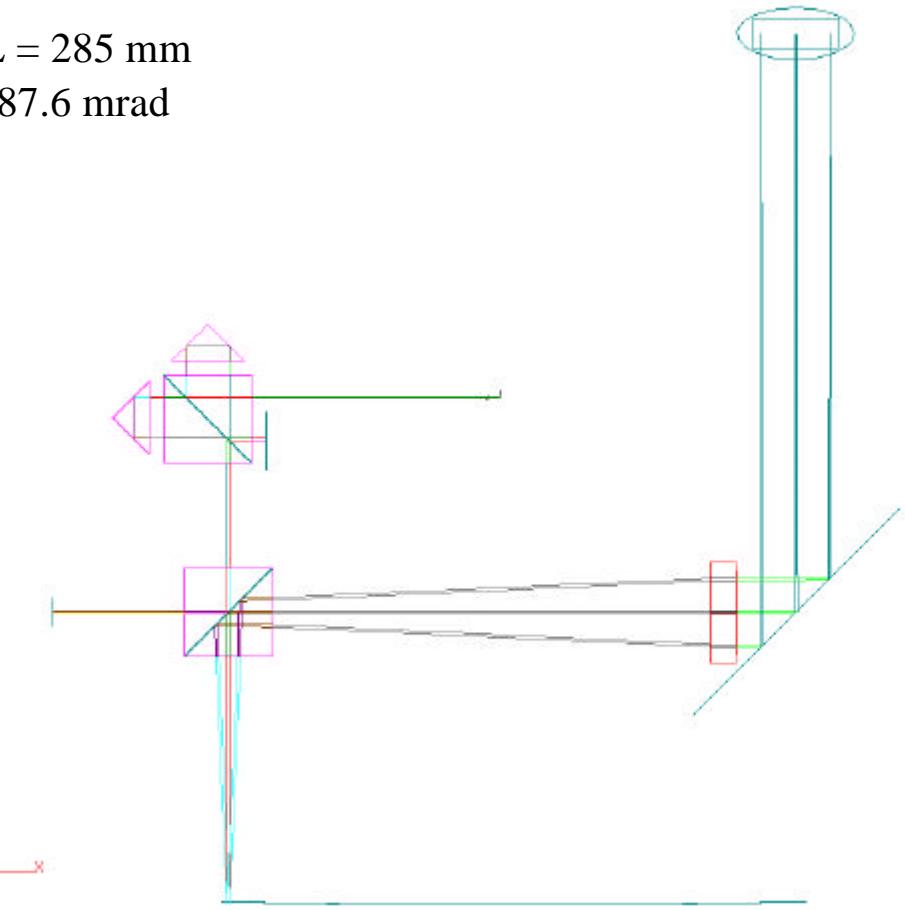
$EFL = 415 \text{ mm}$

$\theta = 60 \text{ mrad}$



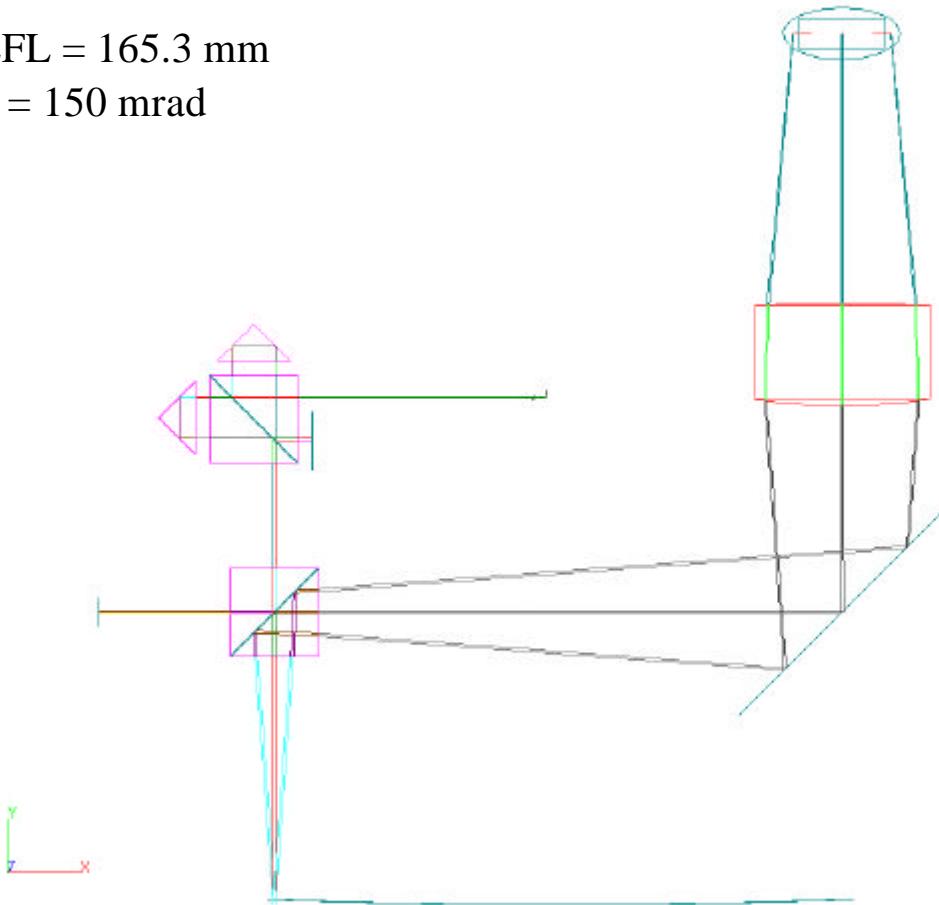
EFL = 285 mm

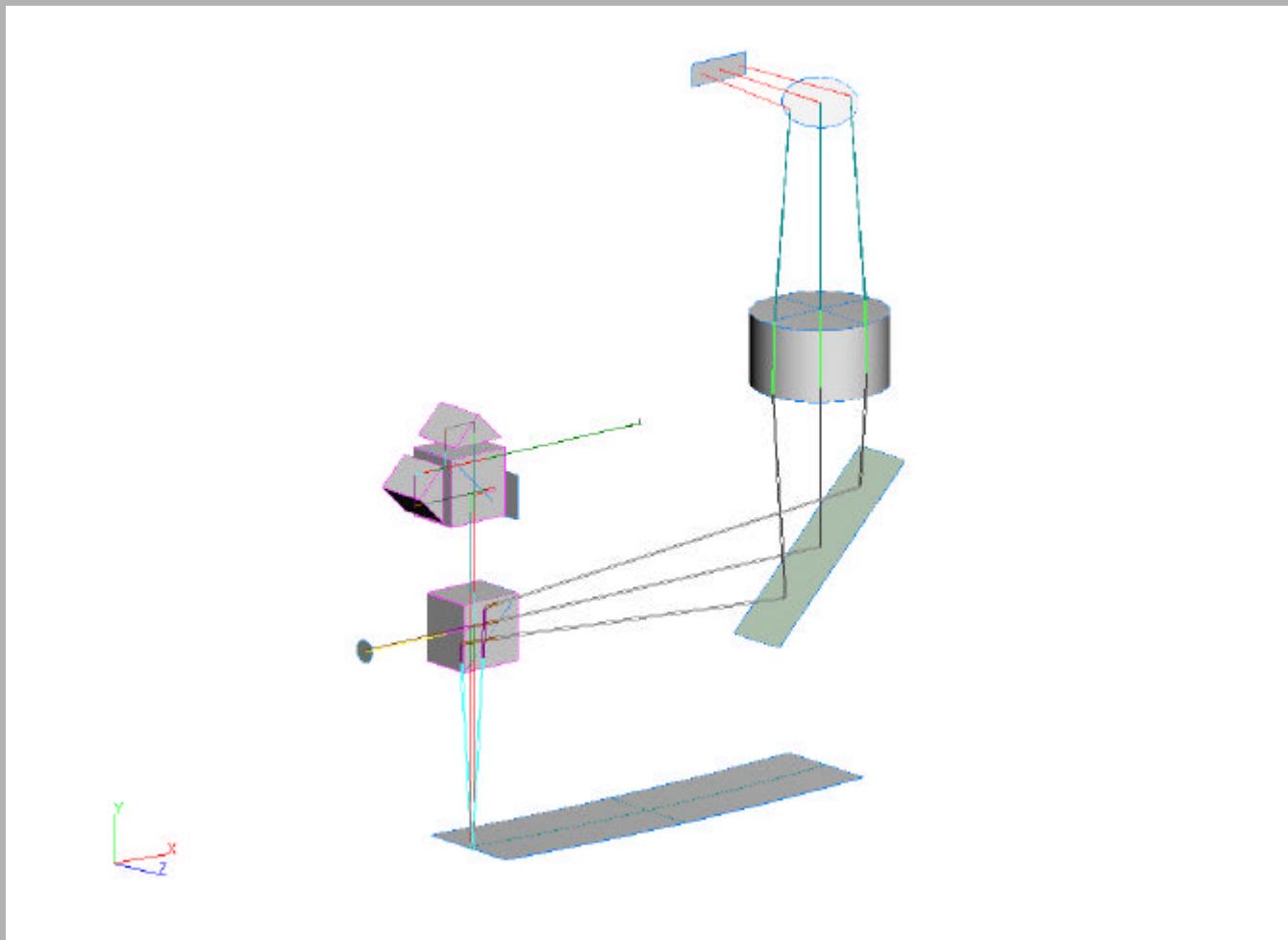
$\theta = 87.6 \text{ mrad}$



$EFL = 165.3 \text{ mm}$

$\theta = 150 \text{ mrad}$





# LTP II Upgrade

## ZEMAX lens design distortion results

Design acceptance	F-θ max distortion		Absolute surface distortion
	D = 100mm	D = 80mm	
60 mrad	<0.0001%	0.002%	15 to 300 nrad
87.6 mrad	0.076%	0.059%	13 to 16 µrad
150 mrad	3.25%	2.80%	1.05 to 1.22mrad
150 mrad 2-lens	0.27%	0.246%	0.10 mrad
150 mrad 3-lens	0.0224%	1.12%	8.4 to 420 µrad

# Acknowledgments

- Photo credits-
  - Dieter Schneider and Toshi Karasawa, AVANCE
- Phase plate fabrication
  - John Warren and Don Elliott
- Shop work
  - Richard Ryder and Bill King

**F I N I S**

## Design projects

- RIKEN ELID head
- BESSY NOK project head
- VLTP for Citterio
- LTP II upgrades
- Portable LTP - OOI detector
- Compact Optical Head
- SPring8 In Situ LTP project

## LTP Improvements

- Super Stable Beamsplitter
- Phase Plate beamsplitter
- OOI commercial version - no air bearing

## LTP I upgrade

- LTP III w/Nikon lenses, Dalsa camera, LabView control and analysis software
- LTP IIIa - open architecture

## Investigations

- Absolute accuracy in long R measurement
- Systematic errors at <1 microradian